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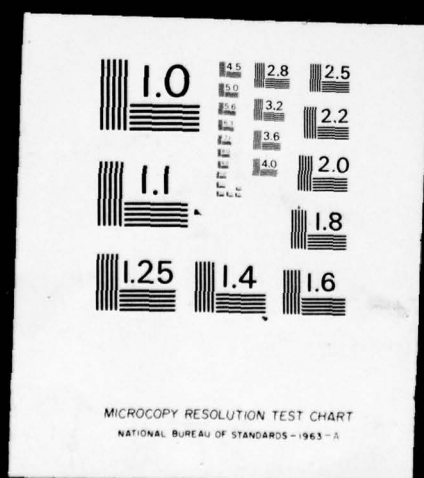
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Production Engineering Measures Program
Manufacturing Methods and Technology

Improvement of Helicopter Forgings
by Controlled Solidification and
Thermal-Mechanical Treatments

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FRANKFORD ARSENAL
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Pitman Dunn Laboratory
Philadelphia, Pennsylvania 19137

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20. ABSTRACT (Continue on reverse side if necessary and identify by block number) A four-task program was conducted to provide information for the development of industrial techniques for producing improved aluminum forgings. These techniques, involving intermediate thermal-mechanical treatment (ITMT) of ingot, were evaluated on the basis of microstructure, mechanical properties, fracture and fatigue properties, and resistance to stress corrosion. The results showed that ITMT forgings have equivalent tensile properties and stress corrosion resistance and at least 20% better fracture toughness and fatigue properties when compared to conventional 7075-T73 forgings.		

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FOREWORD

The Boeing Vertol Company of Philadelphia, Pennsylvania, prepared this report to satisfy the requirements of Contract DAAA25-74-C-0448. This project was accomplished through Frankford Arsenal as part of the U.S. Army Aviation Systems Command Manufacturing Technology program. The primary objective of this program is to develop, on a timely basis, manufacturing processes, techniques and equipment for use in production of Army materiel. Comments are solicited on the potential utilization of the information contained herein as applied to present and/or future production programs. Such comments should be sent to: U.S. Army Aviation Systems Command, ATTN: AMSAV-EXT, P.O. Box 209, St. Louis, Mo. 63166. The U.S. Army Aviation Systems Command project engineer was Mr. James Tutka and the Frankford Arsenal contract technical supervisor was Dr. Jeffrey Waldman.

The Boeing Vertol Company acknowledges the support of the Aluminum Company of America in conducting this program.

Boeing Vertol Company personnel responsible for this program were Leonard J. Marchinski, Director, Structures Technology; Daniel M. Hardy, Program Manager; and Joseph C. Zola, Project Engineer. Aluminum Company of America personnel included Harold Y. Hunsicker, Physical Metallurgy Division Manager; James Staley, Program Manager; and John Vrugink, Project Engineer.

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INTRODUCTION

In recent years, the aluminum industry has directed an intensive effort toward optimizing strength-toughness-stress-corrosion combinations in 2XXX- and 7XXX-series wrought alloys. Examples are 2419, 2124, 2048, 7050, and 7475 in aluminum-alloy plate and 2419, 7049, 7050, and 7175 in aluminum-alloy forgings. Development of these alloys has included work in the areas of alloy chemistry and processing. Reduction of intermetallic particles, both soluble and insoluble, has been broadly exploited.

Future improvements in structural properties, i.e., increased fracture toughness with no loss in strength, can be achieved through the application of microstructure control to products with optimum alloy chemistries to obtain desirable microstructures not now available with conventional processing methods. There are several approaches to controlling microstructure; they include powder metallurgy for wrought products, refinements in ingot-casting technology, advanced and specific thermomechanical treatments during ingot processing to improve and control grain size and morphology, and thermomechanical treatments following the solution-heat-treat operation which would establish new final precipitate and dislocation structures.

The objective of this program is to develop industrially viable fabrication schedules for producing aluminum-alloy forgings which will possess combinations of strength, fracture toughness, fatigue performance, and resistance to stress-corrosion cracking superior to that of 7075-T73.

POWDER METALLURGY

The present powder-metallurgy (P/M) approach, i.e., the work of Cebulak¹, has not only concentrated its efforts in the area of high strength and toughness, but has also emphasized resistance to stress-corrosion cracking. The present P/M alloys offer considerable promise of providing superior combinations of the three properties. P/M alloys were not considered in this study because production quantities of P/M wrought products are not now available. Emphasis has been placed on ingot metallurgy approaches, particularly in the areas of thermomechanical treatment.

FINAL-PROCESSING TMT (FTMT)

References 2 through 7 describe several procedures that involve a combination of thermal and mechanical treatments of 2XXX- and 7XXX-series alloys following solution heat treatment, i.e., prior to or during aging. Such concepts are not new; the T8 tempers of 2XXX alloys have been commercially available for many years. The newer TMT processes differ in that they generally involve preaging at artificial aging temperatures prior to mechanical working. They fall into two general categories:

- Those which seek to improve stress-corrosion resistance while suffering no loss in tensile properties or fracture toughness
- Those which seek to improve tensile strength, while minimizing loss in fracture toughness. These processes have not emphasized stress-corrosion resistance.

The first type, described by Sommer et al², involves elevated-temperature working of a T6-type temper to improve stress-corrosion resistance. The second type, described by a number of workers³⁻⁸, produces strength-toughness combinations which may be attractive for certain high-strength applications of sheet or plate but do not require a high degree of resistance to stress-corrosion cracking. If it were possible to develop adequate stress-corrosion resistance using such methods, it is doubtful that these techniques could be adapted to the closed-die-forging practices which are the ultimate goal of this contract effort.

For these reasons, final-processing TMT was not included in this investigation.

INGOT-PROCESSING TMT (ITMT)

It has been known for some time that a fine, recrystallized grain structure in sheet is a desirable microstructure for high toughness. In sheet form, these structures are usually obtained by cold-rolling prior to and recrystallizing during solution heat treatment.

Producing plate and forgings in a similar manner by cold-working prior to solution heat treatment has not been possible with today's alloys and fabrication procedures, largely because limited ductility prohibits introduction of sufficient cold work. Hence, commercially available, thick-section wrought products often have an unrecrystallized, highly elongated lamellar grain structure which, although desirable for some properties in some directions, is considered detrimental to fracture toughness in the short-transverse direction.

Recently, DiRusso et al⁴ and Waldman et al⁸ developed novel processes specifically designed to produce a fine-grained, recrystallized structure in 7XXX alloy plate. These processes, referred to as Intermediate Thermal-Mechanical Treatments, (ITMT) including establishing a preliminary structure amenable to recrystallization by applying appropriate thermal treatments prior to working at lower-than-conventional working temperatures (in the case of 7X75 plate, the warm-working temperature was 500°F). The warm working introduces relatively high degrees of strain hardening which promote recrystallization to a relatively fine-grained equiaxial grain structure during a subsequent high-temperature thermal treatment. ITMT methods produce products that have either a recrystallized grain structure or an altered grain structure produced by hot working the previously recrystallized structure; the latter procedure elongates the recrystallized grains. The resulting grain morphology is desirable for good fracture toughness and the general fabrication method involved in achieving this structure may be commercially feasible for forgings. For these reasons, the ITMT approach was selected for this study.

To effectively evaluate the advanced processing for applications to forging of hardware, the special technologies of the material producer and the airframe manufacturer have been combined. The material producer, Aluminum Company of America, applied recently developed methods to forging fabrication and the initial optimization of candidate processes. The airframe manufacturer, the Boeing Vertol Company, performed the final evaluation through structural-properties testing of the two most promising candidates identified by the material producer.

The final evaluation includes side-by-side testing of conventional 7075-T73 for comparison with the Intermediate-Thermal-Mechanical-Treatment alloys to permit a valid assessment of the impact of results on the design of helicopter structure.

DISCUSSION

The Boeing Vertol Company, with subcontracted support from the Aluminum Company of America, conducted a four-part program to develop industrial techniques for producing improved aluminum-alloy forgings and to evaluate the forgings for use as components in helicopters.

The primary objective of this program is to develop industrial techniques for producing forgings ranging from 1 to 6.7 inches in section thickness and meeting the target properties shown below:

Tensile Properties	—	Equivalent to or better than 7075-T73
Toughness	—	20% better than 7075-T73
Fatigue Properties	—	20% better than 7075-T73
Stress Corrosion	—	Equivalent to or better than 7075-T73

To achieve this objective, four tasks were identified for accomplishment.

TASK I – SELECT ADVANCED PROCESSES FOR SCALE-UP

Task I was a laboratory-process-optimization effort, concentrating on a combination of alloy-chemistry and alloy-processing method to achieve the best combination of strength, fracture toughness, and resistance to stress-corrosion cracking as indicated by screening tests. Thirty-one advanced-alloy/process combinations or modifications on a 7475 alloy were selected for initial evaluation. The major parameters associated with the advanced processes include chemistry, solidification and homogenization, ingot processing, and thermal/mechanical treatments, and are based primarily on work done by investigators at the Frankford Arsenal, Massachusetts Institute of Technology, and Istituto Sperimentale dei Metalli Leggeri.

One 2 by 8 by 30-inch hand forging with pronounced longitudinal grain-flow characteristics was produced for each of the selected candidate alloy/process combinations. Thermal-mechanical treatment (TMT) was applied during ingot processing to control grain size and grain morphology. The tensile properties, fracture toughness, stress-corrosion resistance, and metallurgical structure of each forging were determined and, on the basis of these results, two optimum TMT practices were selected for scale-up to industrial status.

TASK II – PRODUCE FORGINGS USING CONVENTIONAL AND SCALED-UP ADVANCED PROCESSES

During Task II, scaled-up forgings for detailed testing were produced at Alcoa's Cleveland Works. The test forgings selected are representative of helicopter structural components and were 17 inches wide with section thicknesses of 6.7, 2.0, and 1.0 inch, respectively (see Figure 1). In addition to these three forgings for each optimum TMT process, conventional 7075-T73 forgings were produced in the same sizes. A total of nine scaled-up forgings were produced and delivered to the Boeing Vertol Company.

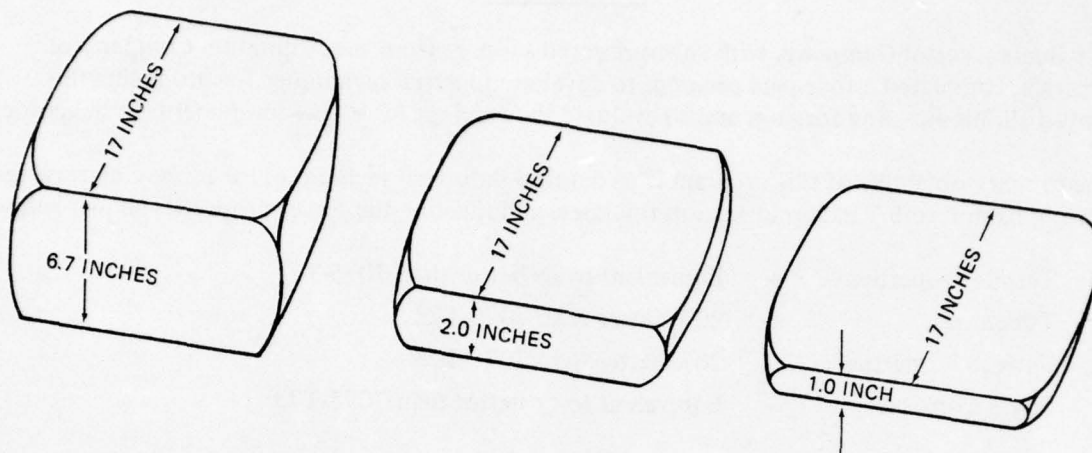


Figure 1. Individual Task II Forgings for Conventional 7075-T73 and 7475-TMT1 and 7475-TMT2 Alloys.

TASK III – CONDUCT MECHANICAL-PROPERTIES TESTS ON FORGING MATERIAL

In this phase of the program the room-temperature mechanical properties of the nine forgings produced in Task II would be determined by test. The following characteristics would be measured:

- a. Tensile properties as determined using ASTM procedures and specimen configuration. Tests would be conducted on specimens with longitudinal grain direction and on specimens with short-transverse grain direction.
- b. Fracture-toughness properties would be determined using a compact-specimen configuration and test procedures per ASTM method E399-72T¹⁰. Properties for the longitudinal and short-transverse grain directions would be established.
- c. Fatigue properties would be determined on axially loaded specimens. Constant-amplitude fatigue-stress levels for testing would be selected with the objective of obtaining data over the life range from 10^4 to 5×10^7 cycles. The influences of stress ratio (minimum stress/maximum stress), stress concentration, and grain direction would be investigated.
- d. Fatigue-crack-propagation properties would be determined using the compact-specimen configuration and constant-amplitude fatigue loading. The influences of an air environment and a salt-solution environment would be investigated. In addition, the properties of the longitudinal and short-transverse grain directions would be determined.
- e. Stress-corrosion-resistance properties would be established using Federal Test Method 823 or the latest recommendation of Joint Aluminum Association-ASTM Task Group for stress-corrosion testing of high-strength 7000-series aluminum alloys.

TASK IV – ANALYZE AND EVALUATE DATA

The objectives of this task are to analyze and evaluate the metallurgical and mechanical-properties data developed in the previous tasks and to assess the impact of improved mechanical properties on the weight and cost of helicopter components.

The influence of the processing on properties will be identified. Primary emphasis will be placed on ranking the candidate processing techniques with respect to their ability to improve tensile, fatigue, fracture, and stress-corrosion-resistance properties. The properties obtained with the advanced-alloy/process combinations will be compared with the properties obtained from the conventionally processed 7075-T73. The parameters used for comparison will include those identified in Table 1.

TABLE 1. COMPARISON OF PROPERTIES

Basis of Comparison	Parameters for Making Comparison
Tensile properties	Tensile ultimate strength Tensile yield strength Elongation Reduction in area
Fatigue properties	Fatigue limit at 5×10^7 cycles S-N curve, fatigue strength as a function of life Goodman diagram, mean-stress/alternating-stress relationship for various constant cyclic lifetimes
Fracture properties	Plane-strain fracture toughness per ASTM 399-70T Notched tensile-strength-to-yield-strength ratio
Fatigue-crack-propagation properties	Fatigue-crack-growth rate as a function of stress-intensity level
Stress-corrosion resistance	Stress levels and times for stress corrosion cracking as identified from testing according to Federal Test Method 823 or Joint Aluminum Association-ASTM task group for stress-corrosion testing

Metallurgical analyses will be directed toward understanding the mechanisms relating the processing and resulting microstructure to the mechanical properties. This will help identify the optimum process for a specific application.

The culmination of the program is the evaluation of the candidate materials for application to helicopter components. The evaluation answers the question, "Is it cost-effective to use these advanced processes to produce forgings for helicopter components?" Obviously, the answer

depends on the details of the specific application. One of the objectives of this analytical task is to provide evaluations for some specific applications and to provide the guidelines whereby the cost-effectiveness of other applications can be evaluated.

Many considerations, such as cost, weight, reliability, and maintainability, govern the design of a helicopter structural component. Weight is a basic concern in such applications and results directly from satisfying structural requirements related to parameters such as static strength, fatigue strength, and failsafe or damage-tolerance strength.

Many current and proposed helicopter dynamic-system components are aluminum forgings; typical components are shown in Figure 2. These components are generally sized by fatigue-strength considerations. Advanced processes for aluminum forgings possessing increased fatigue strength have potential for weight savings in direct proportion to the increase in strength.

The weight-savings potential for helicopter components sized to damage-tolerance requirements will also be evaluated.

Typical weight savings will be determined for various loading criteria. The next step is to establish whether the potential weight savings are cost-effective. This will be achieved through consideration of forging costs, the amount of weight saved, the number of components involved, and the value of a unit of weight in the aircraft cost analysis.

Each task is discussed in detail in the following sections.

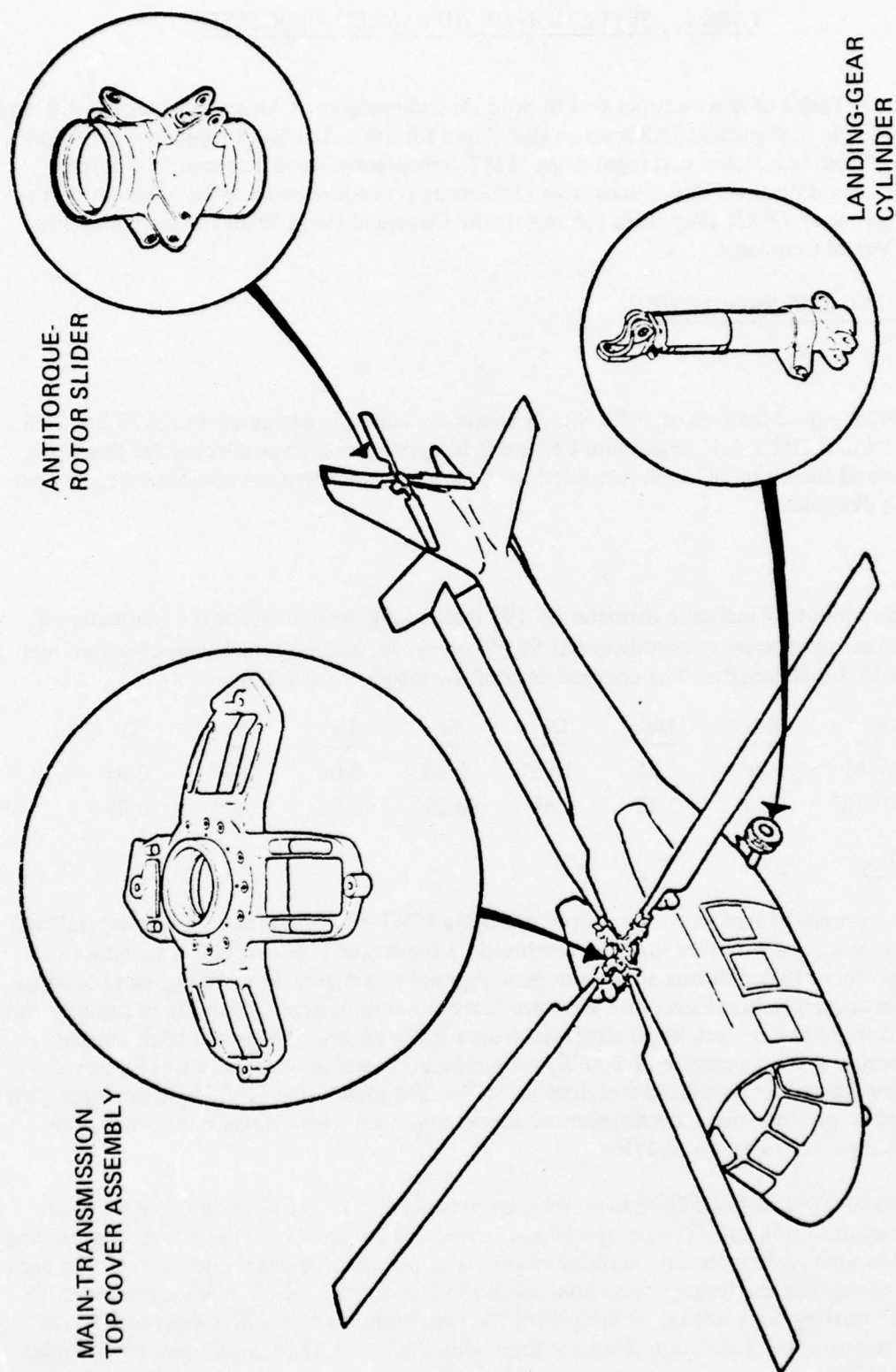


Figure 2. Examples of Forged-Aluminum Components on Current Helicopters.

TASK I - SELECTION OF ADVANCED PROCESSES

The goal of Task I of this contract was to produce and evaluate at Alcoa Laboratories 1.0- and 2.0-inch-thick, high-purity, 7XXX-series alloy hand forgings. The hand forgings were to be produced from laboratory cast ingot using ITMT-type practices and a commercial forging practice. Based on these evaluations, two ITMT-type procedures were to be selected to produce high-purity 7XXX alloy hand forgings at the Cleveland Forge Plant for testing by the Boeing Vertol Company.

MATERIAL AND PROCEDURE

Alloy

Alloy 7475, a modification of 7075, which nominally contains percentages at 5.70 Zn, 2.25 Mg, 1.55 Cu, 0.20 Cr, 0.12 maximum Fe, and 0.10 maximum Si, was selected for this work. The iron and silicon in 7475 are restricted to the lowest values that are considered to be commercially feasible.

Ingot

Direct-chill ingots, 7 inches in diameter by 100 inches long, were used for the fabrication in Task I. The ingots were stress-relieved at 575°F, cropped, scalped to 6.5-inch diameter, and cut into 15.5-inch lengths. The compositions of the ingots are as follows:

<u>S-No.</u>	<u>Zn</u>	<u>Mg</u>	<u>Cu</u>	<u>Cr</u>	<u>Fe</u>	<u>Si</u>	<u>Ti</u>
426669	5.96	2.31	1.63	0.20	0.06	0.04	0.01
437666	5.84	2.23	1.69	0.20	0.06	0.05	0.03

Fabrication

Two broad types of structures were produced using ITMT-type practices: (1) a recrystallized structure, and (2) a structure that was produced by moderately hot-working a structure that had been recrystallized during an intermediate thermal treatment. In addition, hand forgings having an unrecrystallized structure were produced for comparison. Attempts to produce the desired fine-grained recrystallized structure proceeded in phases. The initial trials employed warm-forging at a temperature of 500°F, the temperature which was found to produce the target fine-grained recrystallized structure in 7475 rolled plate using ITMT-type practices. When this failed to produce the desired structure, succeeding trials were carried out using warm-forging temperatures below 500°F.

The 1.0- and 2.0-inch-thick 7475 hand forgings produced in Task I were obtained by a combination of upsetting and drawing operations carried out at various temperatures. The forging operations were carried out, maintaining as closely as possible the desired temperature in each case by suspending the forging operations when the temperature of the billet increased 50°F above the starting temperature, holding until the temperature of the billet decreased to the starting temperature, then continuing the forging operation. If the temperature of the billet

decreased 25°F below the starting temperature during forging, the forging operation was stopped and the billet was reheated to the starting temperature; the forging operation was then continued.

The deformation introduced during each of the forging steps was measured by the value N (N = original dimension in the direction of greatest reduction/final dimension in the direction of greatest reduction). In many of the forging sequences, several N values are required to describe the deformation obtained because the billet was deformed in several directions between succeeding thermal treatments.

The size of the starting ingot sections was restricted by the capacity of the forging press, the size of the dies, and the maximum L/D ratio allowed for upsetting operations. In upsetting an ingot section or forging billet, the relationship between the length of the section in the direction of upsetting and the smallest dimension perpendicular to the direction of upsetting (L/D) is critical. To obtain the proper metal flow, the L/D ratio must be no greater than 3 and in most commercial forging operations involving upsetting the L/D ratio is a maximum of 2.4. In the forging work in Task I, a maximum L/D ratio of 2.4 was used.

The practices used in Phase I to fabricate 1.0- and 2.0-inch-thick 7475-T7X hand forgings by ITMT-type practices are described in detail in Tables 2 and 3. Alloy 7475 hand forgings 1.0 and 2.0 inches thick having an unrecrystallized structure were also produced. Practices patterned after the Frankford Arsenal ITMT (FA-ITMT) plate practice (forgings S-426669-7 and -13) were also included in Phase I. The target fine-grained recrystallized structure was not obtained in the hand forgings fabricated in this phase (500°F forging temperature); consequently lower forging temperatures were investigated in Phase II.

The practices used in Phase II to fabricate 1.0- and 2.0-inch-thick forgings by ITMT-type procedures are described in Tables 4 and 5. These practices evaluated warm-forging temperatures of 350–400°F in conjunction with the same thermal treatments and forging sequences used in Phase I. The target fine-grained recrystallized structure was again not obtained in the hand forgings fabricated in Phase II. The use of the 350°F temperature taxed the capacity of the forging press so this temperature was not used in Phase III. Thus, other thermal treatments and forging sequences were evaluated in Phase III.

The practices used in Phase III to fabricate 1.00- to 2.25-inch-thick forgings by ITMT-type practices are described in Tables 6 and 7. A practice patterned after the Istituto Sperimentale dei Metalli Leggeri (ISML-ITMT) plate practice (forgings S-437666-26A and -26B) and variations in the warm-forging sequences at 400°F were tried in Phase III. Several thicknesses of finished hand forgings were fabricated from the same ingot section by producing stepped hand forgings. An acceptable fine-grained recrystallized structure was obtained in the 1.0-inch-thick portion of a 7475-T7X hand forging produced in Phase III.

The forging practices used in Phases I, II, and III are described pictorially in Figures 3 through 33.

Thermal Treatments

A temperature of 960°F was used for the majority of the ingot preheats*, billet reheats, recrystallization, and solution-heat treatments in this work because prior Alcoa work demonstrated beneficial effects of the 960°F treatments on fracture toughness. (Refer to U.S. Patent No. 3, 791, 880). Work at Alcoa under U.S. Army Contract DAAA25-73-C-0657 showed no adverse effects of a 960°F temperature on the recrystallized grain size of 7475 plate produced using ITMT-type practices. All thermal treatments were carried out using circulating-air furnaces.

Sections of the 1.00- to 2.25-inch-thick 7475 hand forgings were solution-heat-treated, quenched, and artificially aged as indicated in Tables 2 through 7 and in Figure 34.

Grain-Size Determination

The grain dimensions were determined at the T/2 location of the 1.00- to 2.25-inch-thick forgings from grain counts made microscopically using the linear-intercept method. The locations of samples used for the grain counts are shown in Figure 34.

Property Determination

The location, number, and type of specimens used to determine the properties of the forgings are described in Figure 35. The notched-tensile and compact-tension fracture-toughness specimen configurations are shown in Figures 36 and 37. Short-transverse mechanical properties could be determined only on the 2.00- to 2.25-inch-thick forgings because of specimen size limitations.

The resistance to stress-corrosion cracking of selected forgings was determined by exposing stressed specimens to a 3.5-percent NaCl solution by alternate immersion for 84 days as described by Federal Test Method 823. Triplicate longitudinal 0.125-inch-diameter threaded-end tensile specimens from 1.0- and 2.0-inch-thick forgings, similar short-transverse specimens from 2.0-inch-thick forgings, and triplicate short-transverse 0.75-inch-diameter C-rings from 1.0-inch-thick forgings were exposed stressed at a level of 45 ksi.

RESULTS AND DISCUSSION

Grain counts, mechanical-property, and corrosion data are presented in Tables 8 through 16. The mechanical-property values reported are the results of single tests made on the samples aged by each practice. In the following paragraphs, the effects of forging practice on grain dimensions are discussed first, next the effects of yield strength on the mechanical properties, then the relationship between grain structure and the mechanical properties and the effect of grain structure on the resistance to stress-corrosion cracking.

*The use of 960°F thermal treatments on the nonhomogeneous material requires a preheat at lower temperature to eliminate nonequilibrium phases.

ITMT Forging Variables Versus Grain Dimensions

The ITMT-type forging practices in Task I were used to evaluate the merits of nonconventional-type processing and explore the possibility of developing a commercially viable ITMT process to produce a fine-grained recrystallized structure in 7475-T73 hand forgings. The forging practices used were designed to determine whether ITMT practices could produce 7475 hand forgings having a fine-grained recrystallized structure and were not designed to optimize or completely survey the effects of individual fabricating variables. The warm-forging temperature, reduction during warm forging, and reduction during the ingot breakdown by hot-forging at 750°F were not changed in a systematic fashion, and thus the individual effect of each fabricating variable on the grain dimensions of the hand forging is difficult to determine.

The grain counts, average grain dimensions calculated from the grain counts, and the fabricating variables for the forgings produced using ITMT practices are given in Table 16. Three-dimensional photomicrographs at 100X showing the grain structures obtained are included as Figures 3 through 33. The grain thickness, grain width, grain length, and aspect ratio (grain length/grain thickness) of the recrystallized 7475-T7X hand forgings in Table 16 are plotted as functions of the reduction applied during the warm-forging operation (N) in Figure 38. For the forgings produced using sequential warm-forging operations, the value for N used in the plots is the sum of the N values for each separate forging operation.

While no significant relationships were evident between the grain dimensions in the 1.00- to 2.25-inch-thick 7475-T7X ITMT hand forgings and the reductions applied during warm-forging, generalizations concerning the forging operations and the grain structure obtained in the 7475-T7X ITMT hand forgings can be made:

1. Forging the ingot at 750°F prior to warm-forging was beneficial in obtaining a fine-grained recrystallized structure.
2. Warm-forging at a temperature of 400°F produced a finer-grained recrystallized structure in the hand forging than did warm-forging at a temperature of 500°F.
3. Increasing the amount of warm-forging at temperatures of 400°F and 500°F decreased the grain thickness of the recrystallized structure in the forgings.
4. Subsequent forging at 750°F of the prior recrystallized structure increased the aspect ratio of the grains, i.e., decreased the grain thickness and increased the grain length.
5. Reductions of up to $N = 9.1$ at a warm-forging temperature of 550°F and up to $N = 4.4$ at a warm-forging temperature of 500°F did not produce a recrystallized structure in the hand forging when the ingot was not initially forged at 750°F.

Mechanical Properties Versus Yield Strength

Ductility and toughness often correlate with yield strength. Consequently, percentage elongation and reduction-in-area values, notched-tensile-strength/yield-strength ratios, and K_Q values (Tables 8 through 14) were plotted as functions of yield strength for the longitudinal

properties in Figure 39, and for the short-transverse properties in Figure 40. The only consistent relationship found was between longitudinal notched-tensile-strength/yield-strength ratio and the yield strength. The longitudinal notched-tensile-strength ratio decreased with increasing yield strength.

The longitudinal and short-transverse yield strengths were well above the minimum yield strengths specified for 7075-T73 hand forgings up to 3.00-inches in thickness (longitudinal 56.0 ksi and short-transverse 52.0 ksi).

Grain Structure Versus Mechanical Properties

The use of several second-step aging practices provided three sets of mechanical properties for each forging. To minimize the number of data points for graphical analyses to determine the effect of grain dimensions on ductility and toughness, the average elongations and reduction-in-area values and the average notched-tensile-strength/yield-strength ratios for each ITMT forging (Tables 8 through 12), along with maximum and minimum values, were plotted as functions of the grain dimensions. Single K_Q values were also plotted.

The data for the longitudinal direction (Figures 41 through 46) show no consistent change in the elongation, reduction-in-area, notched-tensile-strength/yield-strength ratio, or K_Q values with decreasing grain thickness, decreasing grain width or thickness, or with increasing grain aspect ratios. However, there is an indication that the longitudinal reduction in area increases with decreasing grain thickness.

The short-transverse data (Figures 47 through 50) show that the only consistent change in ductility and toughness with variations in grain dimensions is in the reduction in area and notched-tensile-strength/yield-strength ratio. The reduction in area increased with decreasing grain thickness and the notched-tensile-strength/yield-strength ratio decreased with decreasing grain length or width.

Grain Structure Versus Stress-Corrosion Cracking

The results of accelerated stress-corrosion tests of longitudinal and short-transverse specimens are summarized in Tables 14 and 15, respectively. The results predict that the resistance to stress-corrosion cracking will be relatively high for 7475 hand forgings having a recrystallized-plus-hot-worked structure, a recrystallized structure, or an unrecrystallized structure when aged 24 hours at 250°F plus 8 hours at 350°F. Longitudinal and short-transverse specimens from all forgings tested satisfied the 30-day, 3.5-percent NaCl alternate-immersion-capability test specified for 7075-T73 forgings in MIL-A-22771D.

COMMENTARY

The results of the work carried out in Task I of this contract showed the following:

1. An ITMT-type practice of hot-forging at 750°F, warm-forging at 400°F, and recrystallizing at a temperature of 960°F produced a fine-grained recrystallized structure in 7475-T7X hand forgings.

2. The longitudinal and short-transverse tensile, ductility, and notched-tensile-strength/yield-strength ratios were similar for 7475-T7X hand forgings having a recrystallized-plus-hot-worked structure and an unrecrystallized structure.
3. The longitudinal notched-tensile-strength/yield-strength ratios and K_Q values obtained on 7475-T7X hand forgings, regardless of the structure, were superior to similar properties of 7075 hand forgings at the same strength level.

TABLE 2. FORGING PRACTICES USED TO FABRICATE 1-INCH-THICK 7475-T7X HAND FORGINGS IN PHASE I

Forging Operation				6.5 ϕ x 15.5-In. Ingot Section				Forged Billet				Recrystallization		Forging by Drawing at 750°F, Reduction, N	Solution-Heat-Treat Temperature (°F)					
S.No.	Size (in.)	Grain Count, G/mm			Forging Operation			Size (in.)	Thermal Treatment (°F)	Forging Operation		Size (in.)	Thermal Treatment							
		X	Y	Z	Temp (°F)	Type	Reduction, N			Temp (°F)	Type					Reduction, N				
426669-8	1x8x64	4	2	24	A	750	Upset & draw	2.8	7x8x9	A	500	Draw	7.0	1x8x64	10 hr/960°F	None	2 hr/960			
426669-9	1x8x64	8	3	24	A	750	Upset & draw	2.8	4x8x16	A	500	Draw	4.0	1x8x64	10 hr/960°F	None	2 hr/960			
42669-10	1x8x64	5	3	20	A	750	Upset & draw	2.8	2x8x32	A	500	Draw	2.0	1x8x64	10 hr/960°F	None	2 hr/960			
426669-11	1x8x64	3	2	40	A	750	Upset & draw	2.8	7x8x9	A	500	Draw	4.1	1.7x8x38	10 hr/960°F	1.7	2 hr/960			
426669-12	1x8x64	5	2	43	A	750	Upset & draw	2.8	3.5x8x16	A	500	Draw	2.1	1.7x8x38	10 hr/960°F	1.7	2 hr/960			
426669-13	1x8x64	1	1	19	B	500	Upset & draw	9.1	→ 1.7x8x38									10 hr/860°F	1.7	2 hr/860
426669-14	1x8x64	Unrecrystallized														→ 2 hr/960				

NOTES:

- Ingot thermal treatments: A heated 6 hours at 860°F plus 20 hours at 960°F; B heated 20 hours at 860°F, cooled to 775°F at 50°F/hour, soaked 2 hours at 775°F, cooled to 500°F at 50°F/hour, and soaked at least 4 hours at 500°F.
- Forged-billet thermal treatment: A heated 2 hours 960°F, cooled to 775°F at 50°F/hour, soaked 2 hours at 775°F, cooled to 500°F at 50°F/hour, and soaked at least 4 hours at 500°F.
- All thermal treatments carried out in circulating-air furnaces.

NOTES: 1. Ingot thermal treatments: A heated 6 hours at 860°F plus 20 hours at 960°F; B heated 20 hours at 860°F, cooled to 775°F at 50°F/hour, soaked 2 hours at 775°F, cooled to 500°F at 50°F/hour, and soaked at least 4 hours at 500°F.
2. Forged-billet thermal treatment: A heated 2 hours 960°F, cooled to 775°F at 50°F/hour, soaked 2 hours at 775°F, cooled to 500°F at 50°F/hour, and soaked at least 4 hours at 500°F.
3. All thermal treatments carried out in circulating-air furnaces.

TABLE 4. FORGING PRACTICES USED TO FABRICATE 1-INCH-THICK 7475-T7X HAND FORGINGS IN PHASE II

Final Forging				6.5 ϕ x 15.5-In. Ingot Section				Forged Billet				Recrystallization		Forging by Drawing at 750°F, Reduction, N	Solution-Heat-Treat Temperature (°F)	
S.No.	Size (in.)	Grain Count, G/mm			Forging Operation			Size (in.)	Thermal Treatment	Temp (°F)	Reduction, N	Size (in.)	Thermal Treatment			
		X	Y	Z	Temp (°F)	Type	Reduction, N									
426669-17	1x8x64	2	2	24	B	400	Upset & draw	15.5	—	—	—	1x8x64	10 hr/860°F	None	2 hr/860	
426669-18	1x8x64	5	3	25	C	400	Upset & draw	15.5	—	—	—	1x8x64	10 hr/960°F	None	2 hr/960	
426669-19	1x8x64	6	3	50	A	750	Upset & draw	2.8	—	—	—	—	—	—	—	
426669-20	1x8x64	6	3	16	A	750	Upset & draw	3.1	5x8x13	A	400	Upset & draw	7.7	1.7x8x38	10 hr/960°F	2 hr/960
426669-22	1x8x64	2	1	22	B	750	Upset & draw	3.1	5x8x13	A	400	Upset & draw	1.3	1x8x64	10 hr/960°F	2 hr/960
426669-23	1x8x85	3	2	30	B	400	Upset & draw	9.1	—	—	—	1.7x8x38	10 hr/860°F	1.7	2 hr/860	
						350	Upset & draw	15.5	—	—	—	1x6x85	10 hr/860°F	None	2 hr/860	

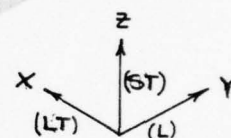
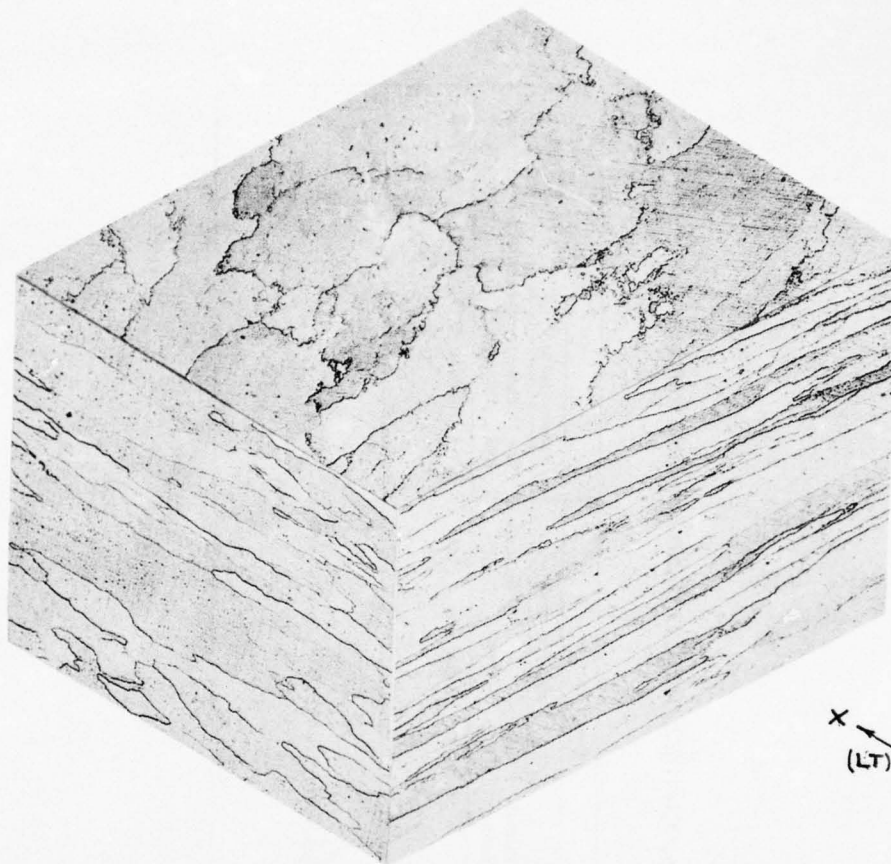
NOTES:

- Ingot thermal treatments: A heated 6 hours at 860°F plus 20 hours at 960°F; B heated 20 hours at 860°F, cooled to 775°F at 50°F/hour, soaked 2 hours at 775°F, cooled to 500°F at 50°F/hour, and soaked at least 4 hours at 500°F; C heated 6 hours at 860°F plus 20 hours at 960°F, cooled to 775°F at 50°F/hour, soaked 2 hours at 775°F, cooled to 500°F at 50°F/hour, and soaked at least 4 hours at 500°F.
- Forged-billet thermal treatment: A heated 2 hours at 960°F, cooled to 775°F at 50°F/hour, soaked 2 hours at 775°F, cooled to 500°F/hour, and soaked at least 4 hours at 500°F.
- All thermal treatments carried out in circulating-air furnaces.

NOTES: 1. Ingot thermal treatments: A heated 6 hours at 860°F plus 20 hours at 960°F; B heated 20 hours at 860°F, cooled to 775°F at 50°F/hour, soaked 2 hours at 775°F, cooled to 500°F at 50°F/hour, and soaked at least 4 hours at 500°F; C heated 6 hours at 860°F plus 20 hours at 960°F, cooled to 775°F at 50°F/hour, soaked 2 hours at 775°F, cooled to 500°F at 50°F/hour, and soaked at least 4 hours at 500°F.

2. Forged-billet thermal treatment: A heated 2 hours at 960°F, cooled to 775°F at 50°F/hour, soaked 2 hours at 775°F, cooled to 500°F at 50°F/hour, and soaked at least 4 hours at 500°F.

3. All thermal treatments carried out in circulating-air furnaces.



MAG 100X
2.00" THICK 7475-T7X HAND FORGING

KELLER'S ETCH

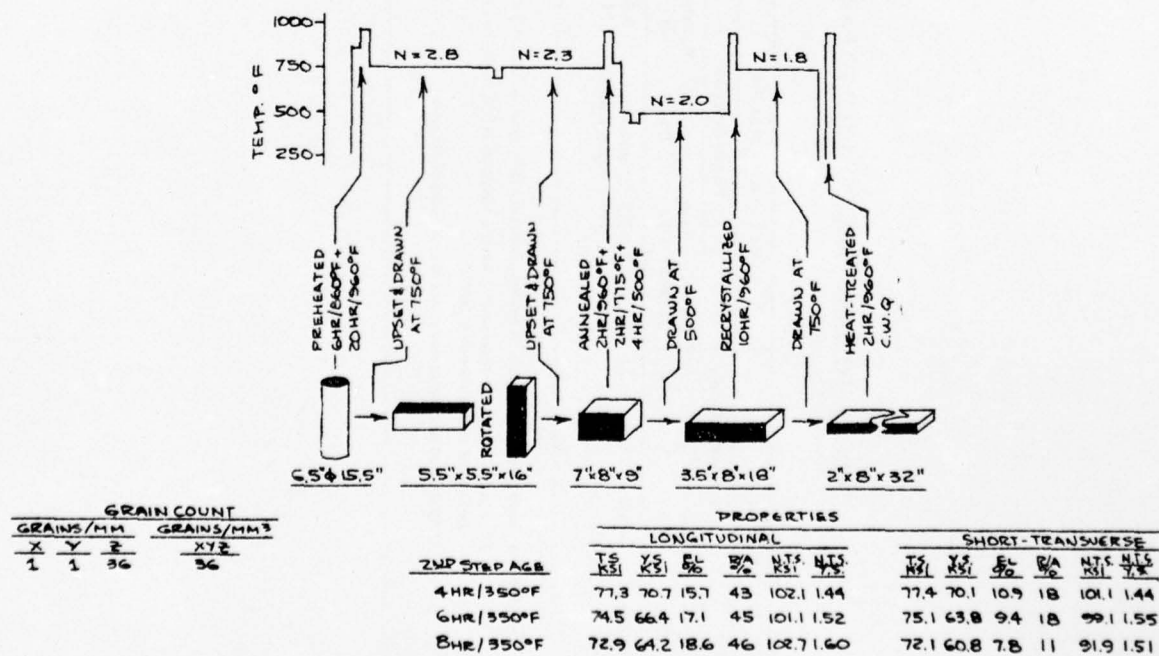
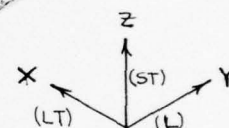
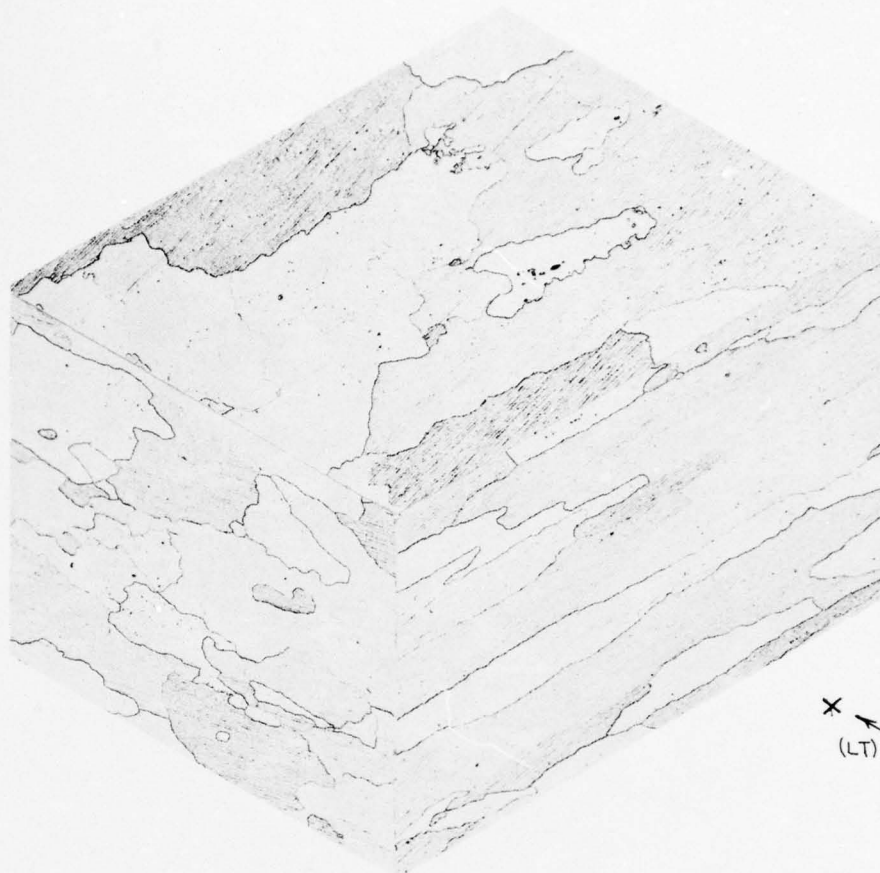
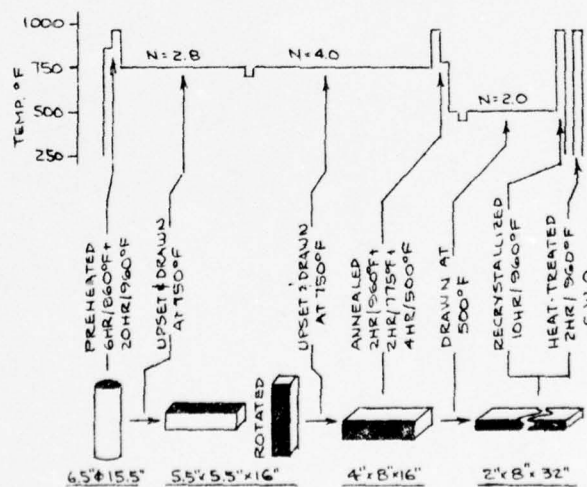


Figure 3. Microstructure, Properties, and Forging Practice for 2-Inch-Thick 7475-T7X Hand Forging S-426669-1.



MAG. 100X
2.00" THICK 7475-T7X HAND FORGING

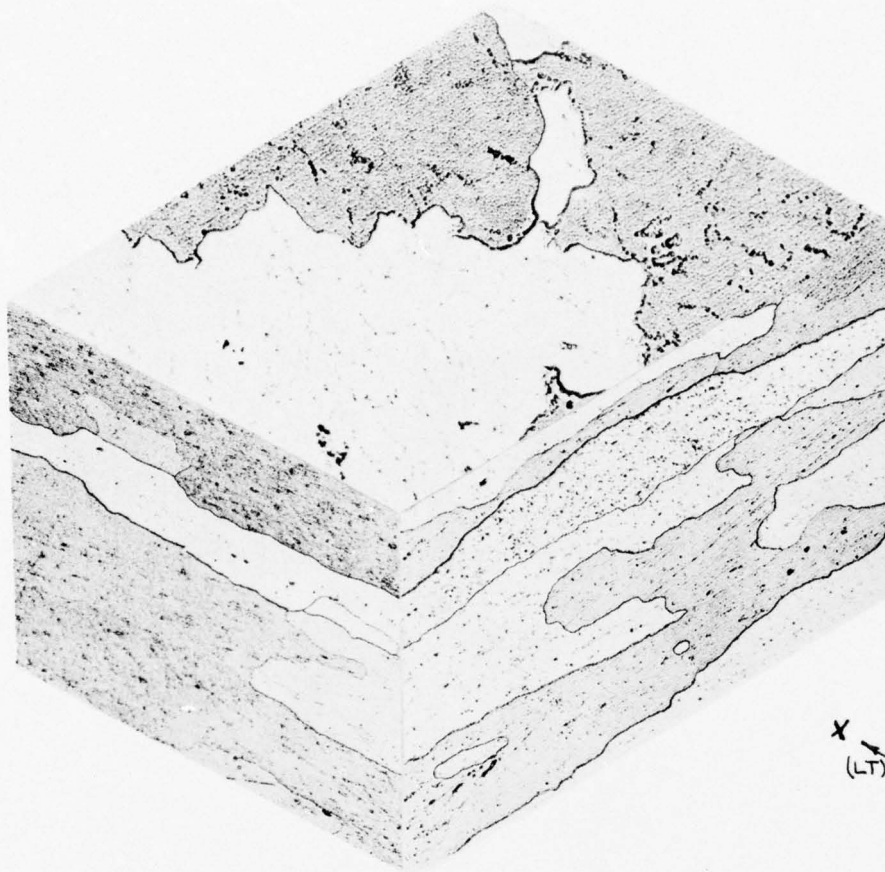
KELLER'S ETCH



GRAIN COUNTS				
GRAINS/MM			GRAINS/MM ²	
X	Y	Z	XYZ	
7	2	19	266	

2ND STEP AGE	LONGITUDINAL						SHORT-TRANSVERSE					
	T.S.	Y.S.	EL.	RA	NTS	UTS	T.S.	Y.S.	EL.	RA	NTS	UTS
4HR/350°F	78.3	70.7	14.3	19	103.2	1.46	79.1	68.7	6.2	6	89.9	1.31
6HR/350°F	76.9	67.9	12.9	24	98.6	1.45	78.4	66.4	5.4	11	91.9	1.38
8HR/350°F	74.9	65.4	13.6	30	99.1	1.51	73.1	65.7	4.7	6	93.0	1.42

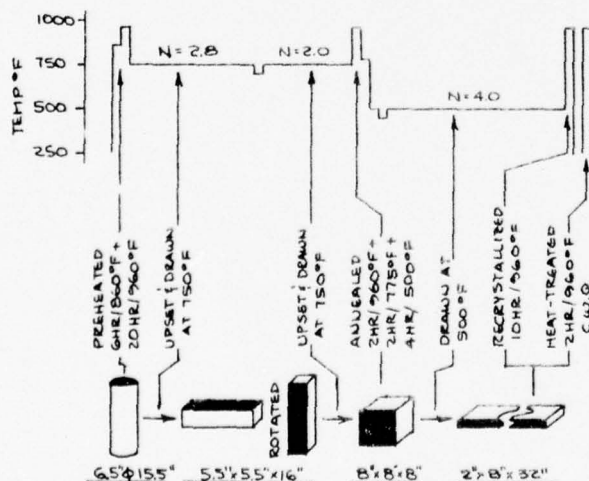
Figure 4. Microstructure, Properties, and Forging Practice for 2-Inch-Thick 7475-T7X Hand Forging S-426669-2.



MAG 100X

KELLER'S ETCH

2.00" THICK 7475-T7X HAND FORGING



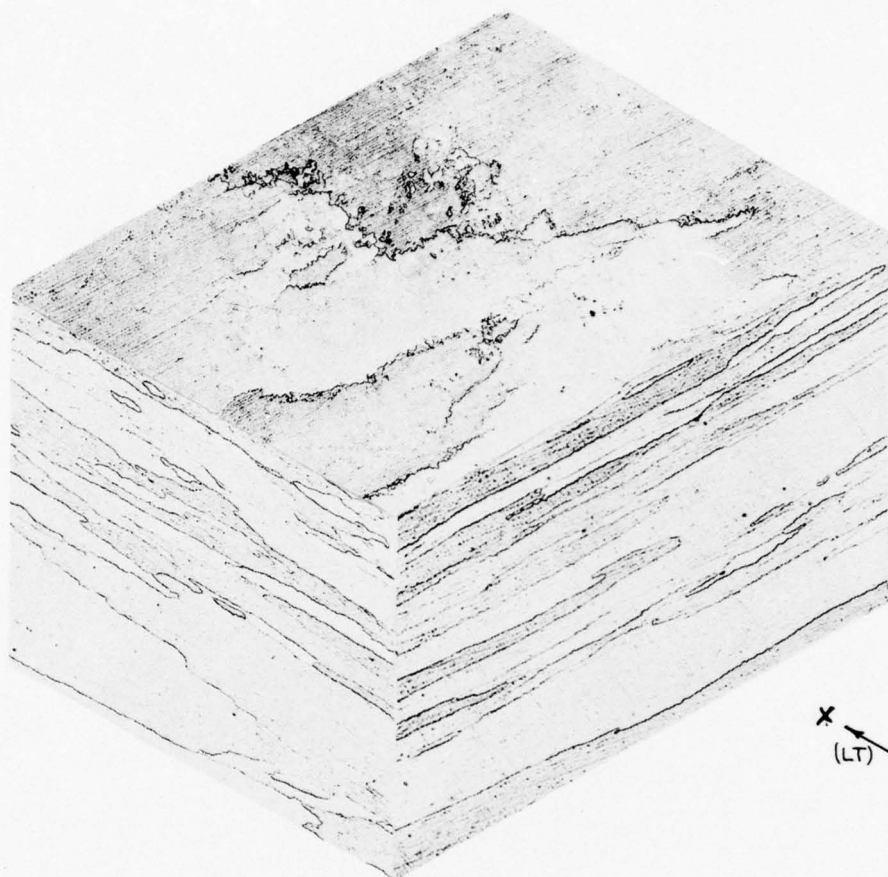
GRAIN COUNT			
GRAINS/MM		GRAINS/MM ³	
X	Y	Z	XYZ
1	1	6	6

2ND STEP AGE			
4HR/350°F	773	709	143
6HR/350°F	751	674	143
8HR/350°F	739	659	136

LONGITUDINAL					
T _S	T _S	EL	B/A	NTS	NTS
773	709	143	27	98.6	1.39
751	674	143	30	98.6	1.46
739	659	136	30	99.6	1.51

SHORT-TRANSVERSE					
T _S	T _S	EL	B/A	NTS	NTS
746	679	4.7	7	90.4	1.33
736	631	7.8	7	99.6	1.57
731	627	7.8	11	95.0	1.52

Figure 5. Microstructure, Properties, and Forging Practice for 2-Inch-Thick 7475-T7X Hand Forging S-426669-3.



MAG 100X

KELLERS ETCH

2.00" THICK 7475-T7X HAND FORGING

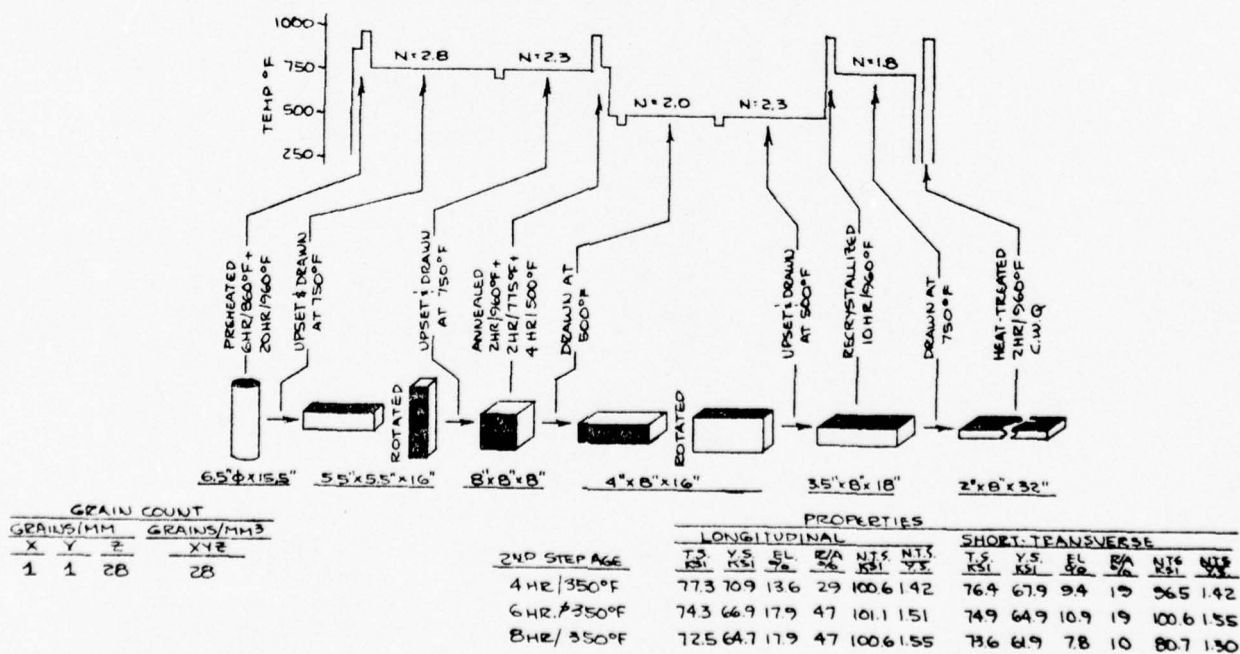
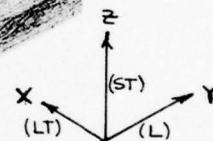
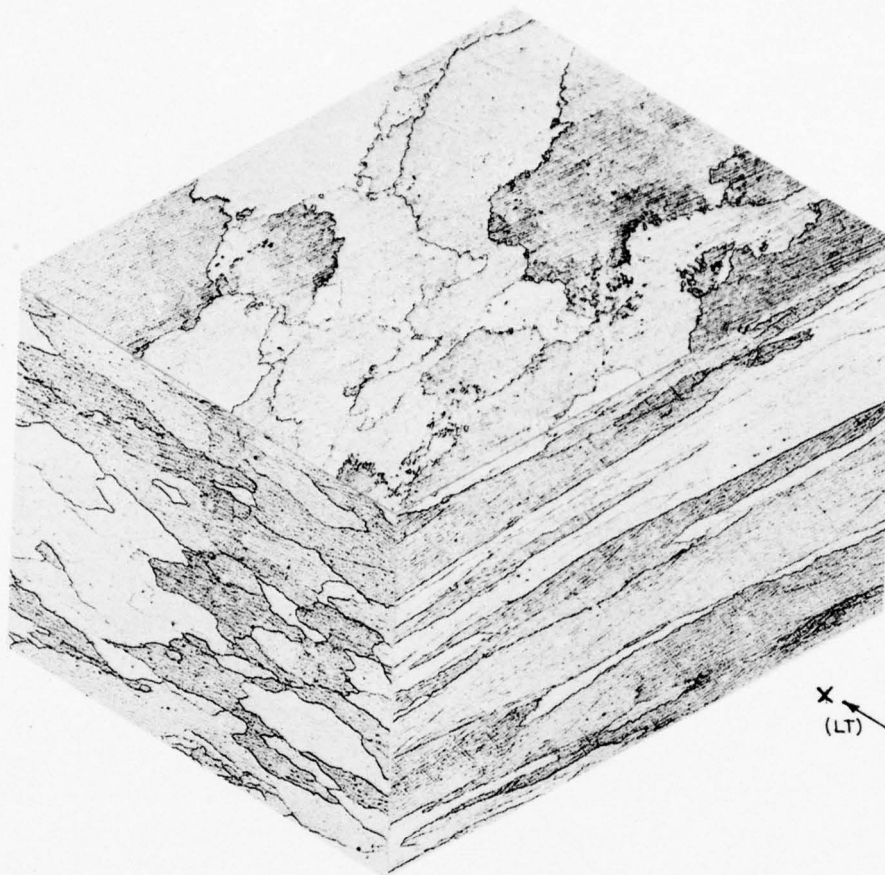


Figure 6. Microstructure, Properties, and Forging Practice for 2-Inch-Thick 7475-T7X Hand Forging S-426669-5.



MAG 100X
2.00" THICK 7475-T7X HAND FORGING

KELLER'S ETCH

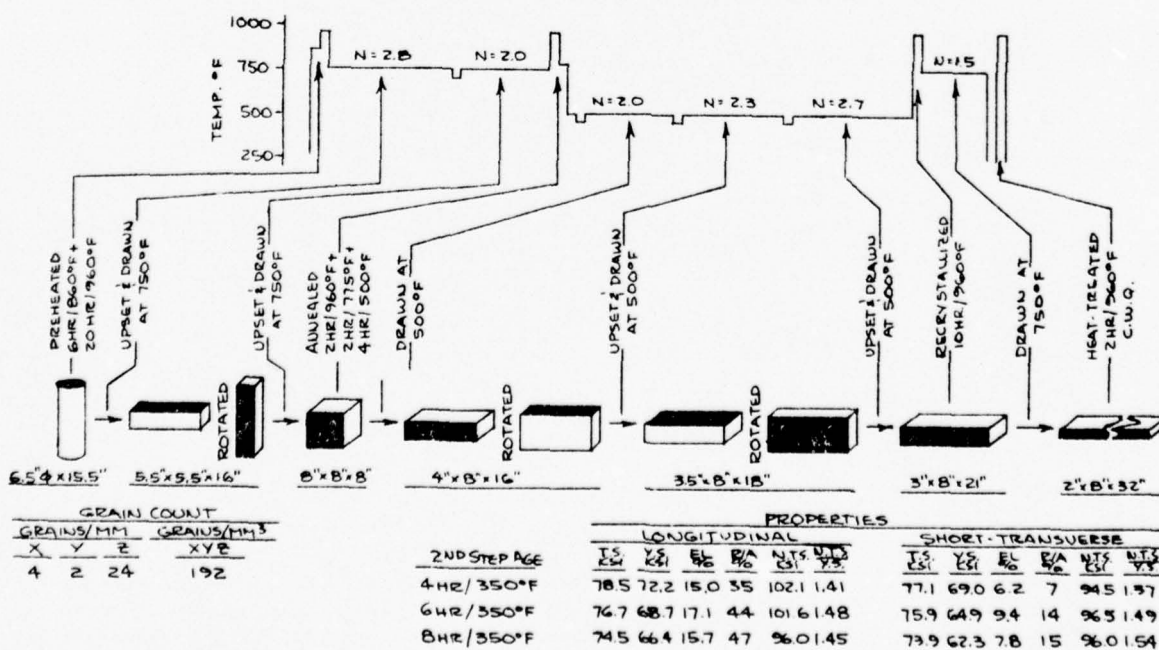
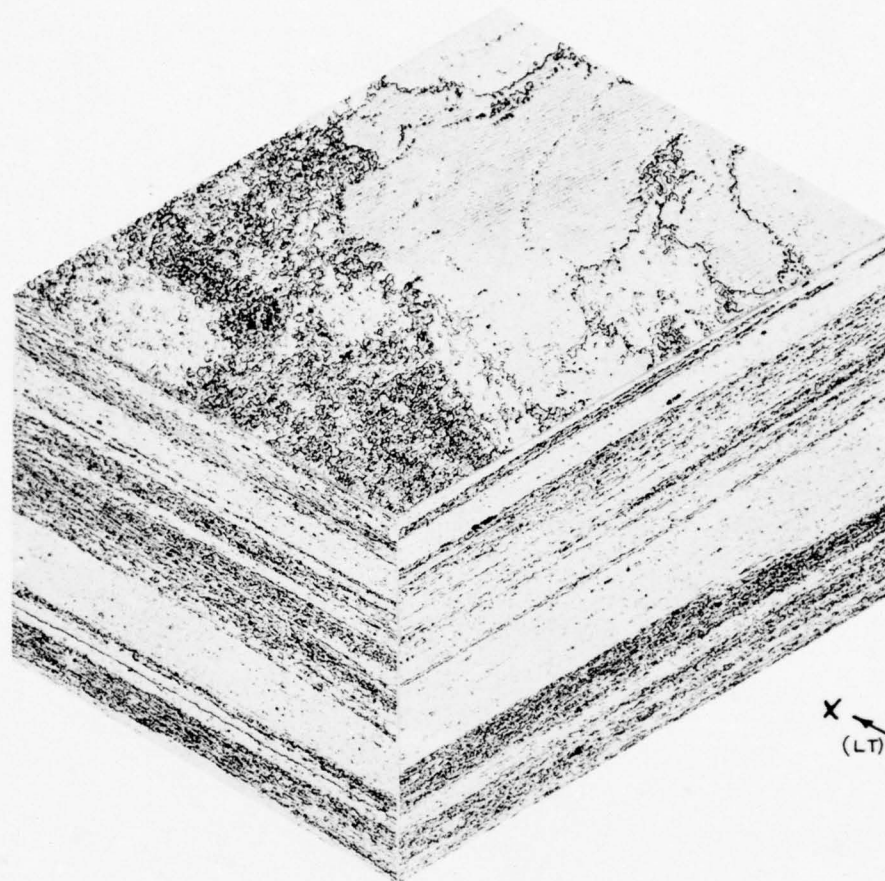


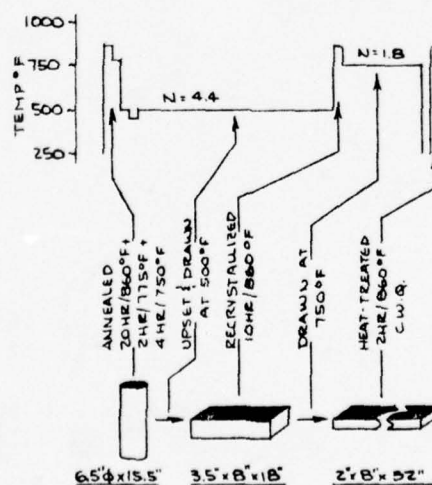
Figure 7. Microstructure, Properties, and Forging Practice for 2-Inch-Thick 7475-T7X Hand Forging S-426669-6.



MAG 100X

KELLER'S ETCH

2.00" THICK 7475-T7X HAND FORGING

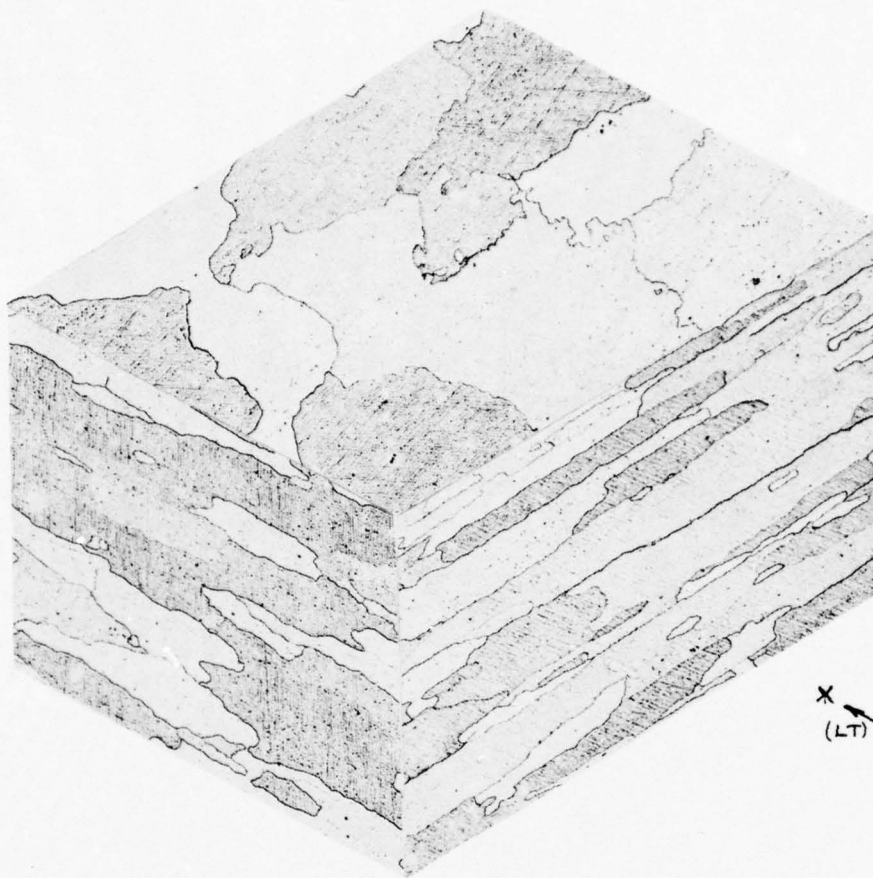


GRAIN COUNT			
GRAINS/MM		GRAINS/MM ²	
X	Y	X	Y

UNRECRYSTALLIZED

2UP STEP AGE	PROPERTIES							
	LONGITUDINAL				SHORT-TRANSVERSE			
	T _S	Y _S	EL	R/A	T _S	Y _S	EL	R/A
4 HR / 350°F	73.3	64.9	14.3	33	95.0	1.46	74.1	66.3
6 HR / 350°F	70.9	61.2	14.3	32	92.4	1.51	69.7	60.4
8 HR / 350°F	70.7	60.4	15.0	29	95.0	1.57	70.6	57.8

Figure 8. Microstructure, Properties, and Forging Practice for 2-Inch-Thick 7475-T7X Hand Forging S-426669-7.



MAG 100X

KELLER'S ETCH

1.00" THICK 7475-T7X HAND FORGING

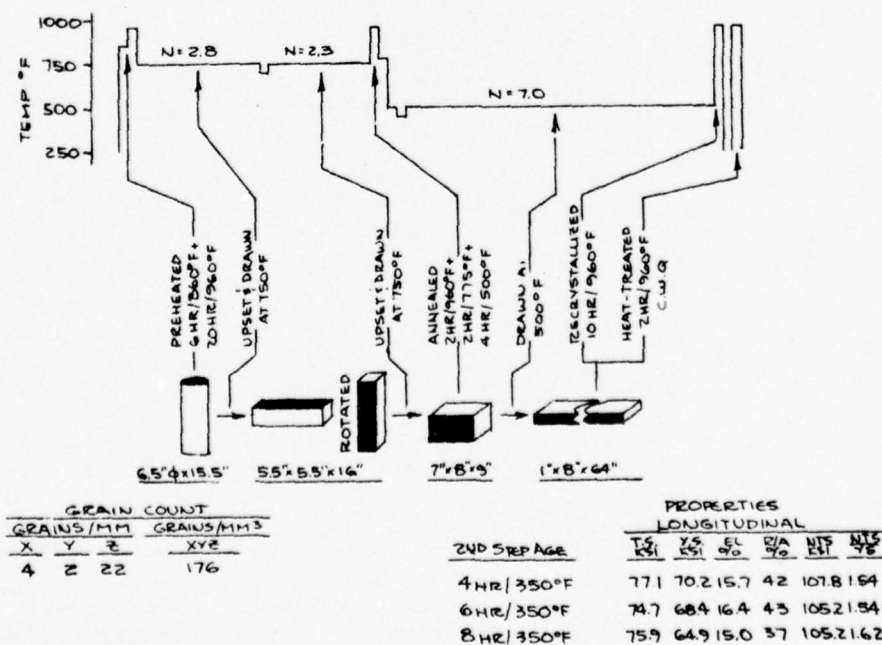
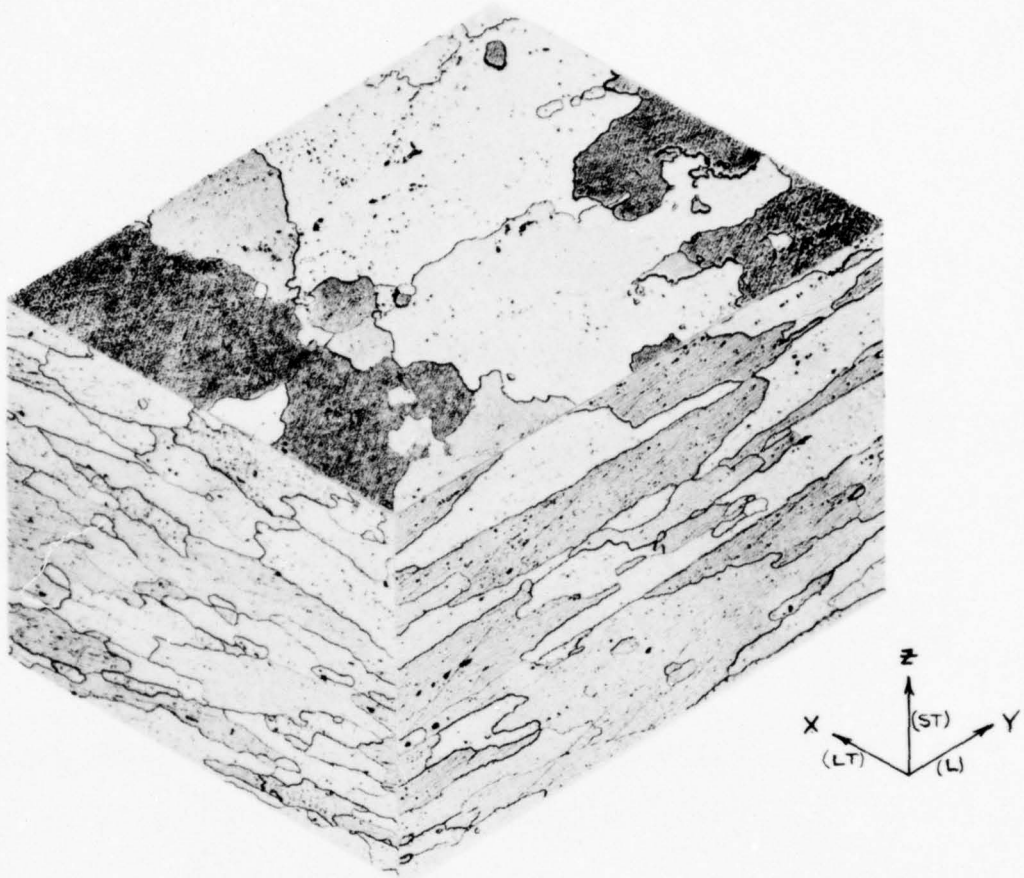


Figure 9. Microstructure, Properties, and Forging Practice for 1-Inch-Thick 7475-T7X Hand Forging S-426669-8.



MAG 100X

KELLER'S ETCH

1.00" THICK 7475-T7X HAND FORGING

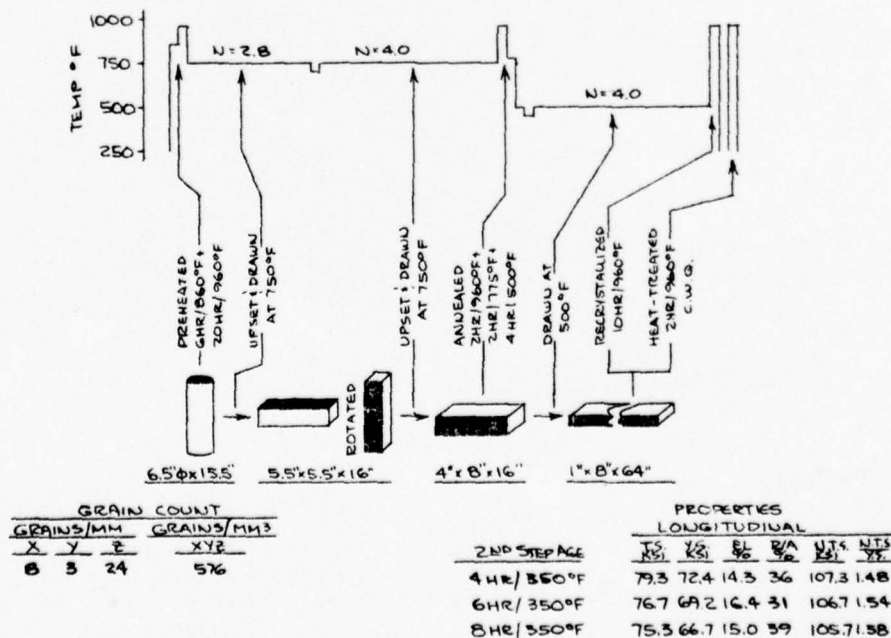
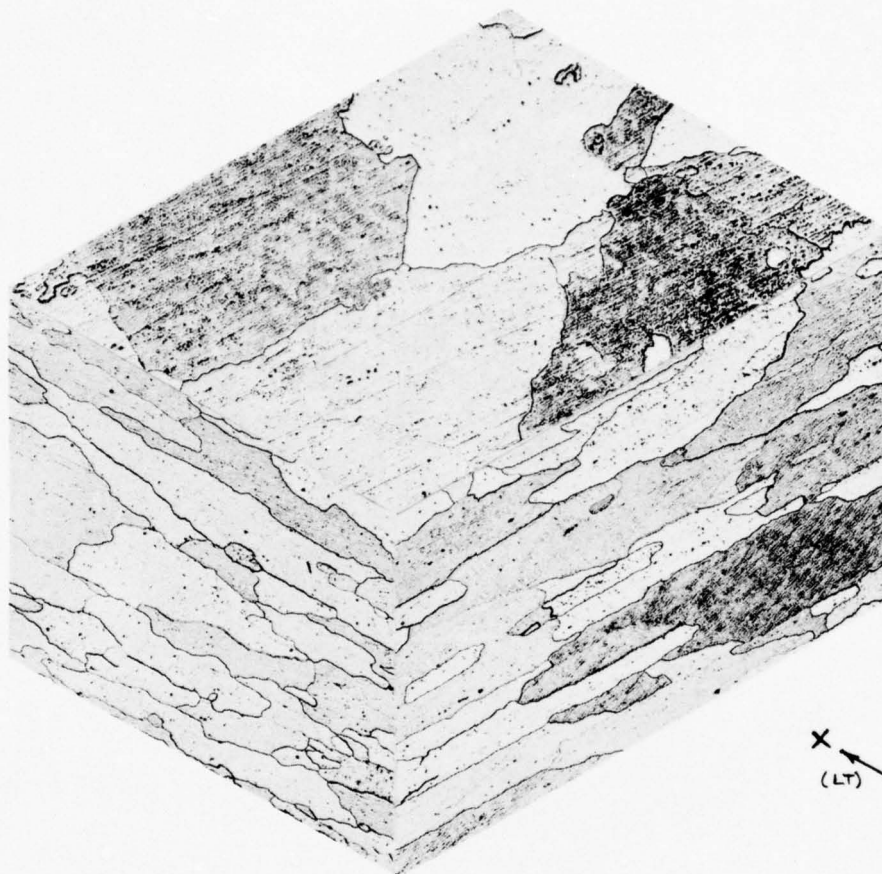


Figure 10. Microstructure, Properties, and Forging Practice for 1-Inch-Thick 7475-T7X Hand Forging S-426669-9.



MAG 100X

KELLER'S ETCH

1.00" THICK 7475-T7X HAND FORGING

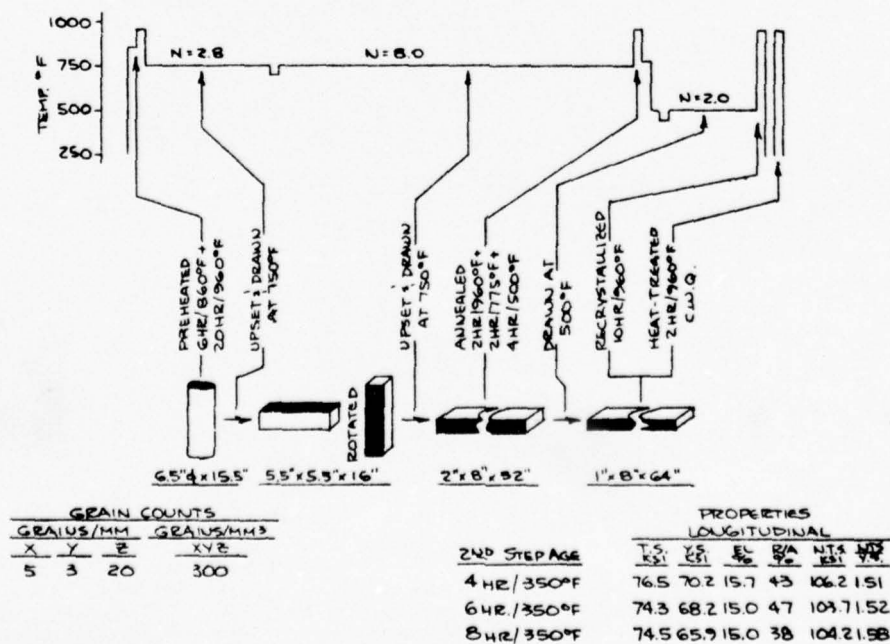
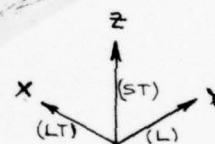
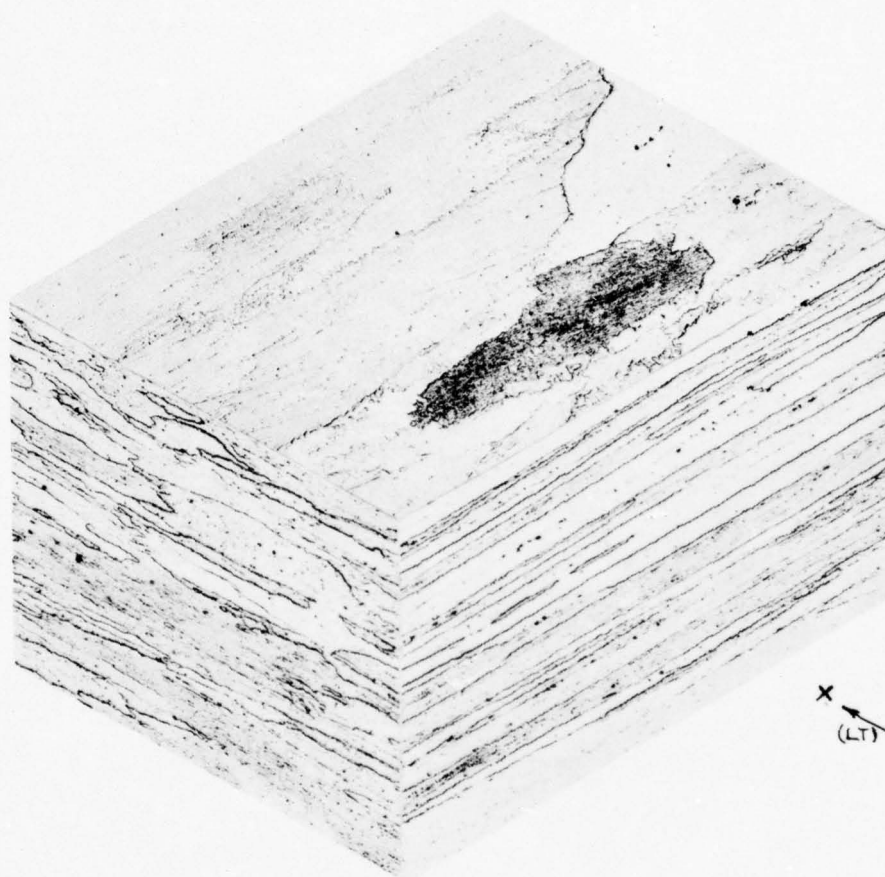


Figure 11. Microstructure, Properties, and Forging Practice for 1-Inch-Thick 7475-T7X Hand Forging S-426669-10.



MAG 100X

KELLER'S ETCH

1.00" THICK 7475-T7X HAND FORGING

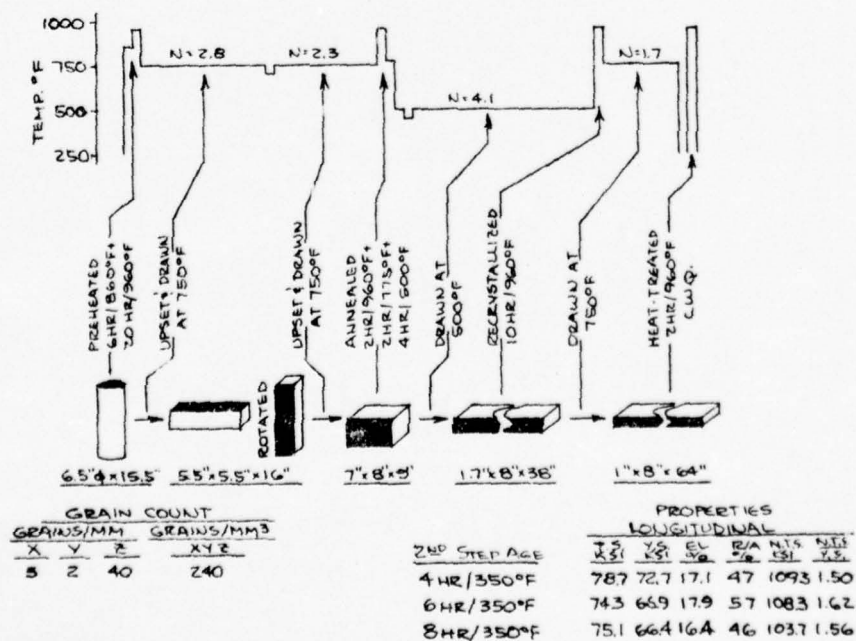
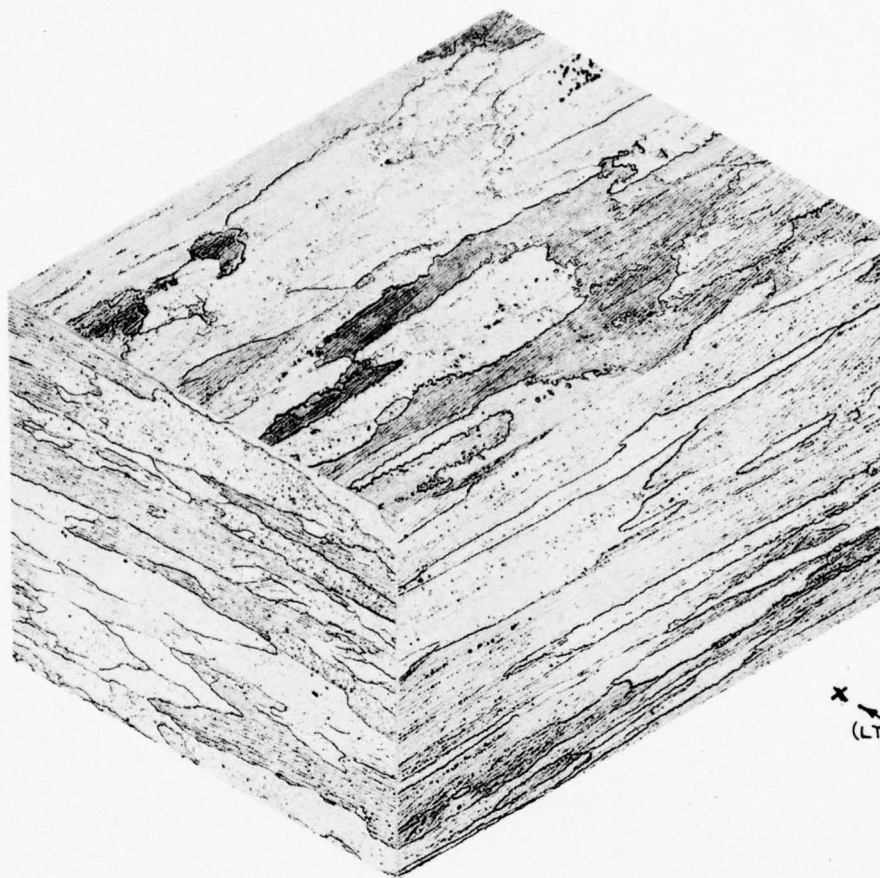


Figure 12. Microstructure, Properties, and Forging Practice for 1-Inch-Thick 7475-T7X Hand Forging S-426669-11.



MAG 100X

KELLER'S ETCH

1.00" THICK 7475-T7X HAND FORGING

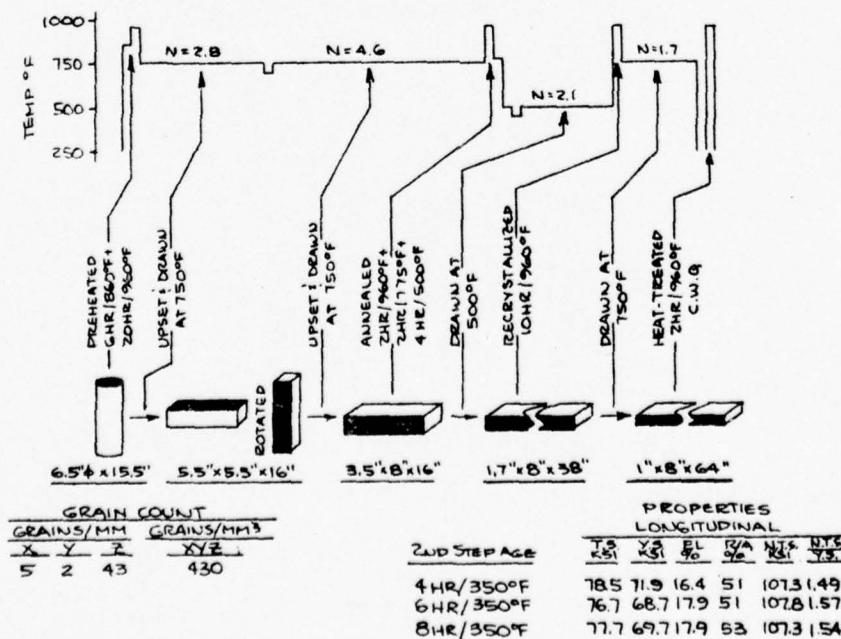
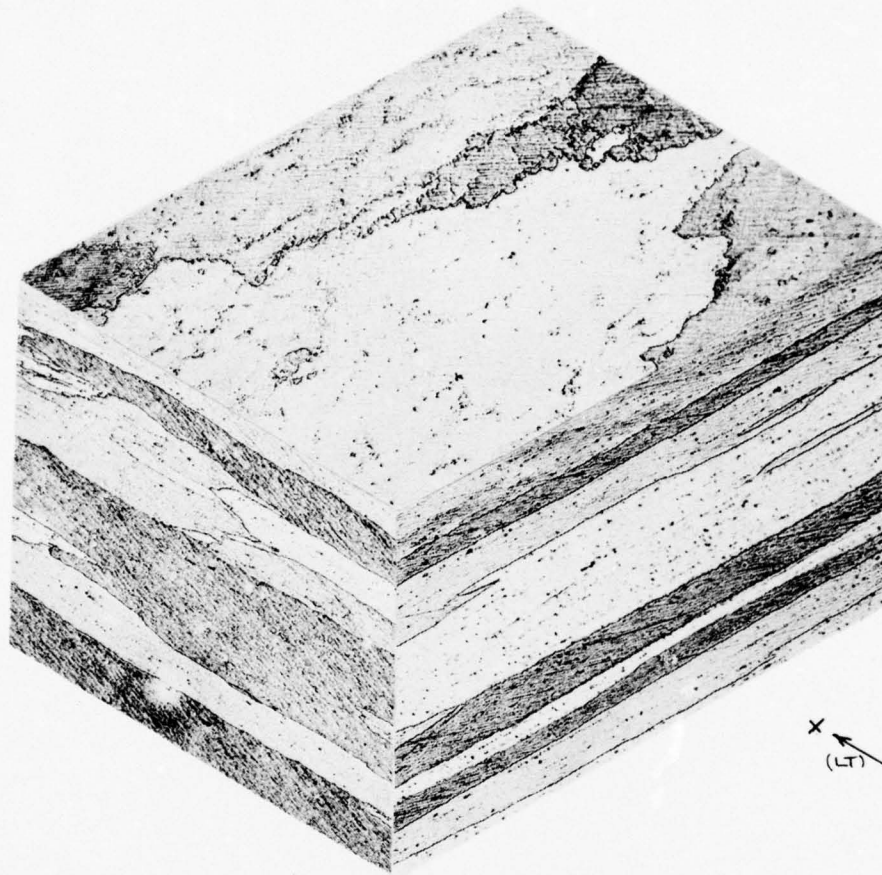


Figure 13. Microstructure, Properties, and Forging Practice for 1-Inch-Thick 7475-T7X Hand Forging S-426669-12.



MAG 100X

1.00" THICK 7475-T7X HAND FORGING

KELLER'S ETCH

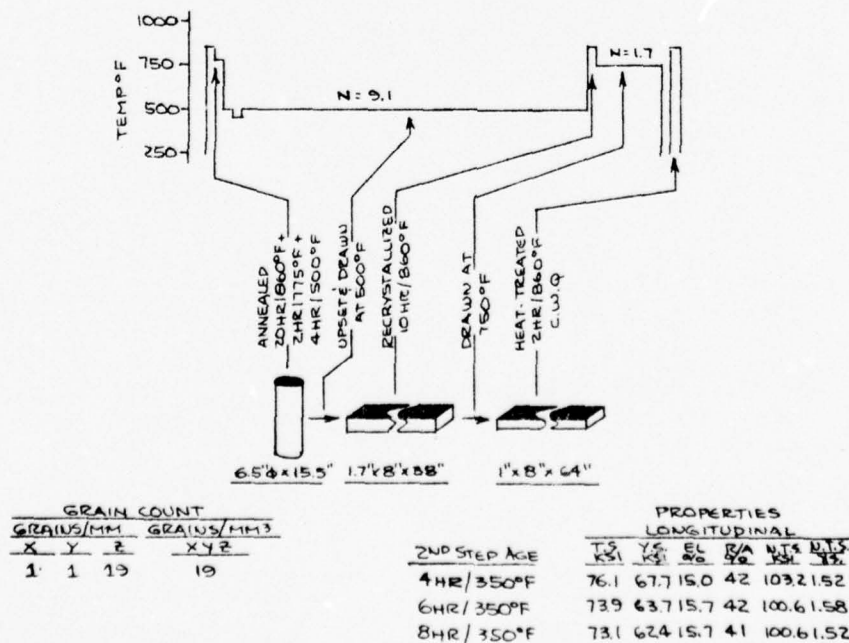
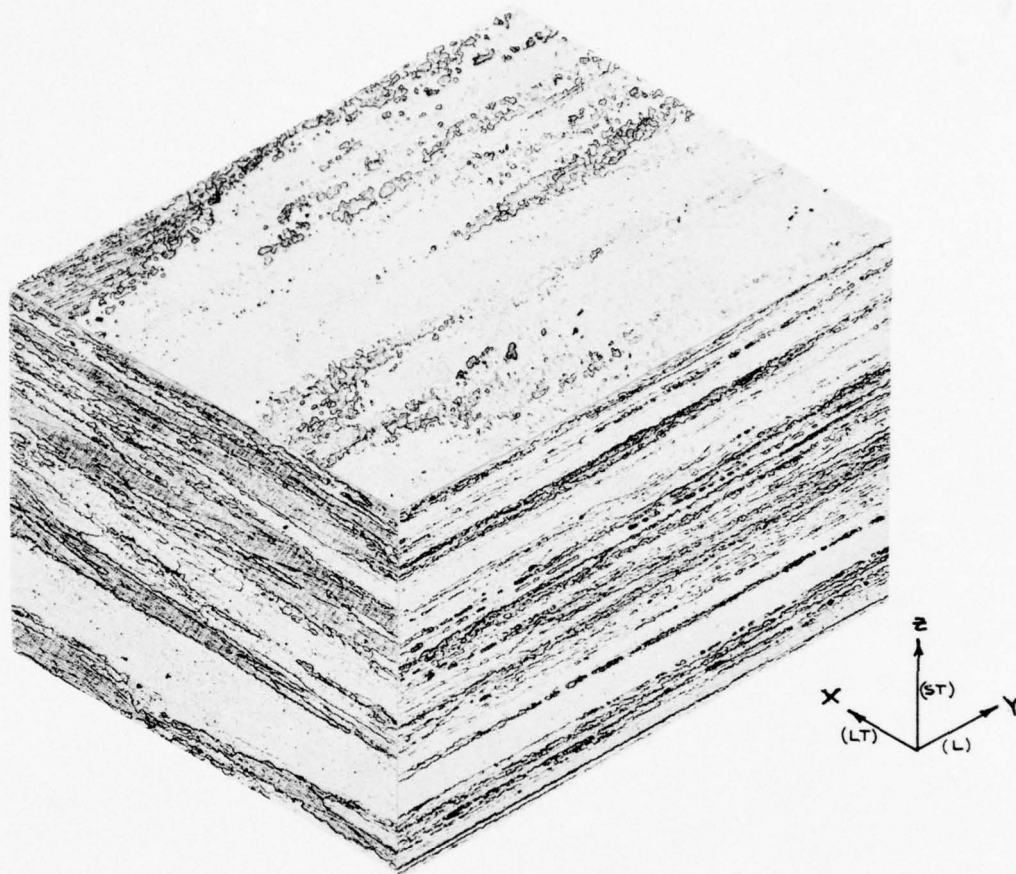


Figure 14. Microstructure, Properties, and Forging Practice for 1-Inch-Thick 7475-T7X Hand Forging S-426669-13.



MAG 100X

1.00" THICK 7475-T7X HAND FORGING

KELLEY'S ETCH

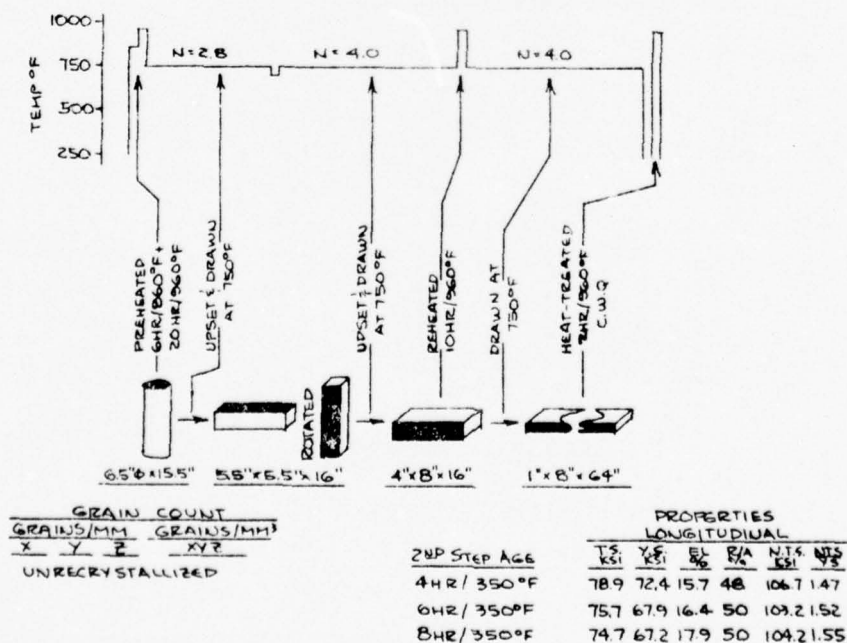
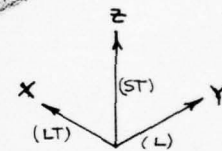
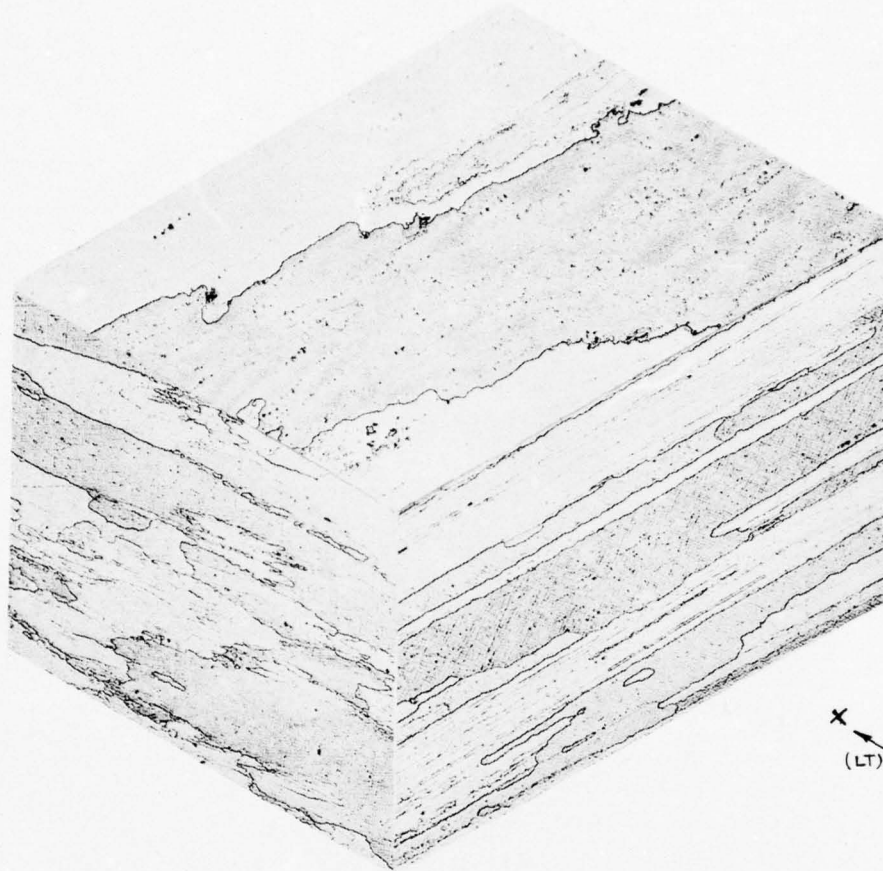


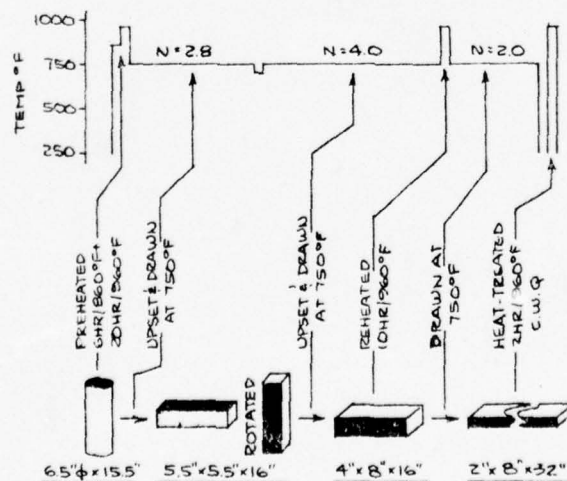
Figure 15. Microstructure, Properties, and Forging Practice for 1-Inch-Thick 7475-T7X Hand Forging S-426669-14.



MAG 100X

KELLER'S ETCH

2.00" THICK 7475-T7X HAND FORGING



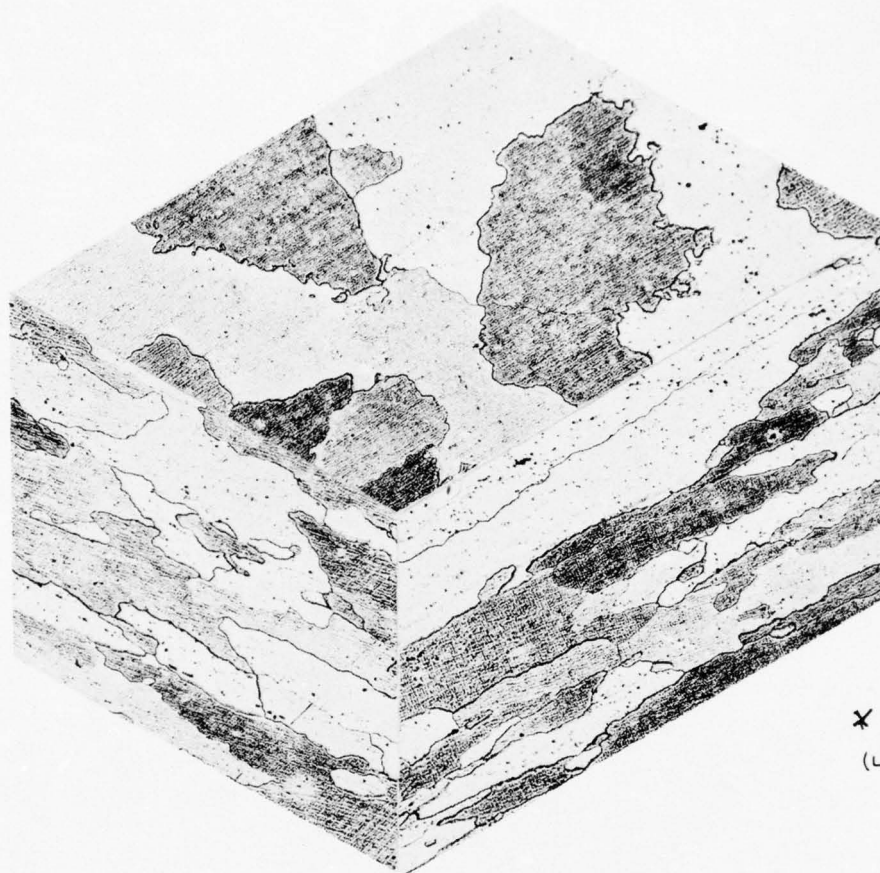
GRAIN COUNT			
GRAINS/MM	GRAINS/MM	GRAINS/MM	GRAINS/MM
X	Y	Z	XYZ
UNRECRYSTALLIZED			

2ND STEP AGE

4HR/350°F
6HR/350°F
8HR/350°F

PROPERTIES							
LONGITUDINAL						SHORT-TRANSVERSE	
TS	YS	EL	B/A	UTS	UTS	TS	YS
78.7	72.2	12.9	27	101.6	1.41	77.1	70.1
76.7	69.2	15.0	41	103.7	1.50	75.9	67.9
73.1	64.4	17.9	49	99.1	1.54	72.4	64.9

Figure 16. Microstructure, Properties, and Forging Practice for 2-Inch-Thick 7475-T7X Hand Forging S-426669-15.



MAG 100X

2.00" THICK 7475-T7X HAND FORGING

KELLER'S ETCH

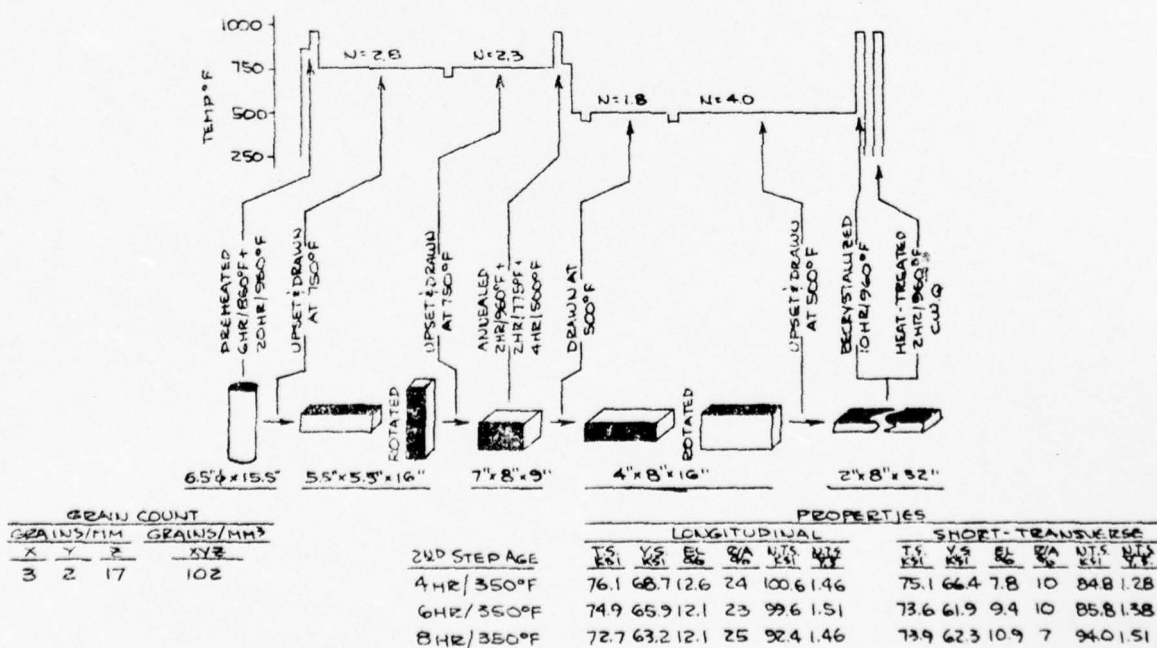
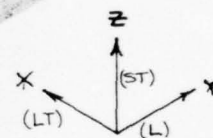
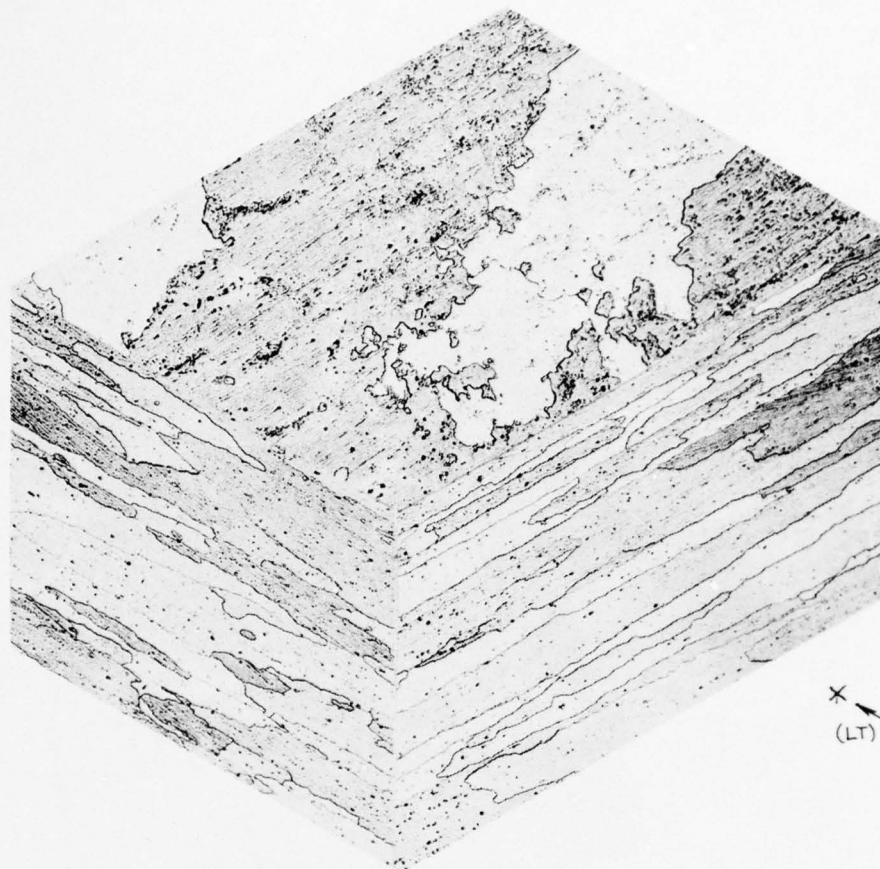
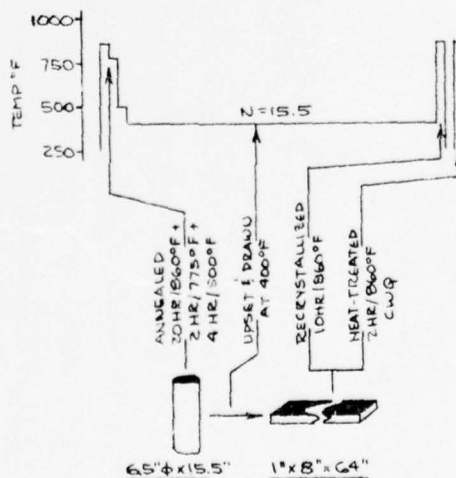


Figure 17. Microstructure, Properties, and Forging Practice for 2-Inch-Thick 7475-T7X Hand Forging S-426669-16.



MAG 100X
1.00" THICK 7475-T7X HAND FORGING

KELLER'S ETCH



GRAIN COUNT			GRAINS/MM ²
X	Y	Z	
2	2	24	96

2ND STEP AGE

4 HR / 350°F

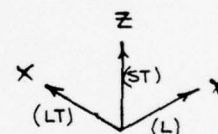
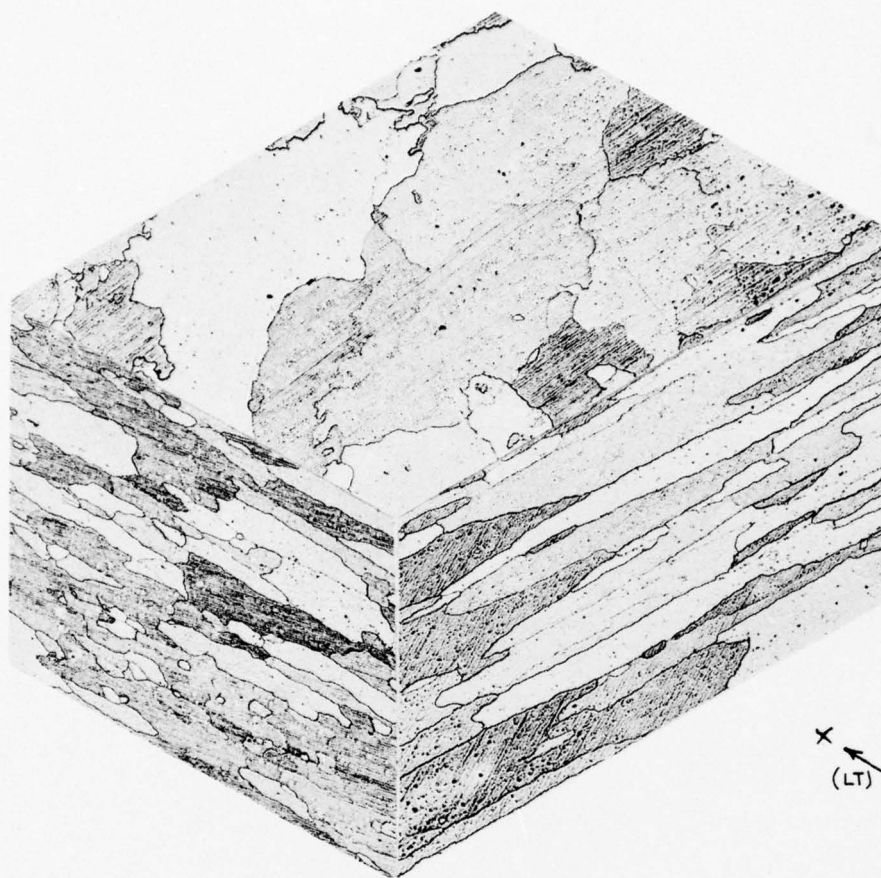
6 HR / 350°F

8 HR / 350°F

PROPERTIES
LONGITUDINAL

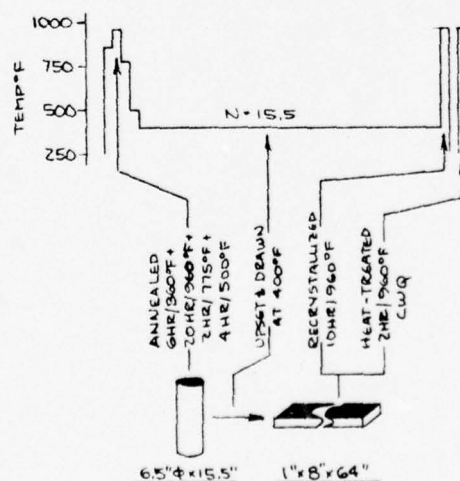
T.S. KSI	YS KSI	EL %	R/A %	NTS EL	NTS YS
76.1	67.4	14.3	38	102.7	1.52
75.9	65.2	17.1	43	99.6	1.53
73.1	62.9	13.6	40	99.3	1.58

Figure 18. Microstructure, Properties, and Forging Practice for 1-Inch-Thick 7475-T7X Hand Forging S-426669-17.



MAG100X
1.00" THICK 7475-T7X HAND FORGING

KELLER'S ETCH

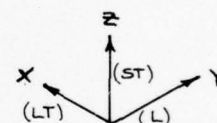
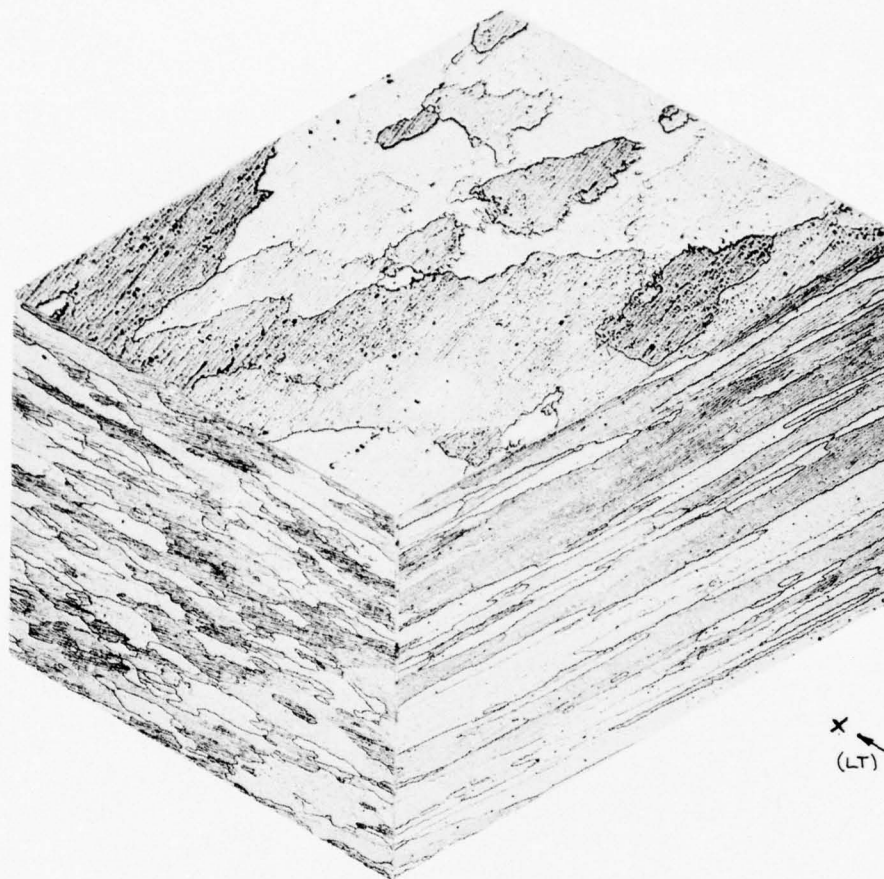


GRAIN COUNT				
GRAINS/MM			GRAINS/MM ²	
X	Y	Z	XY	Z
5	3	25	375	

2ND STEP AGE
4HR/350°F
6HR/350°F
8HR/350°F

PROPERTIES LONGITUDINAL					
CS	YS	EL	RA	UTS	UTB
77.9	71.2	15.7	38	104.7	147
76.1	68.4	15.7	38	103.2	151
73.5	65.4	15.7	45	102.7	157

Figure 19. Microstructure, Properties, and Forging Practice for 1-Inch-Thick 7475-T7X Hand Forging S-426669-18.



MAG 100X

KELLER'S ETCH

1.00" THICK 7475-T7X HAND FORGING

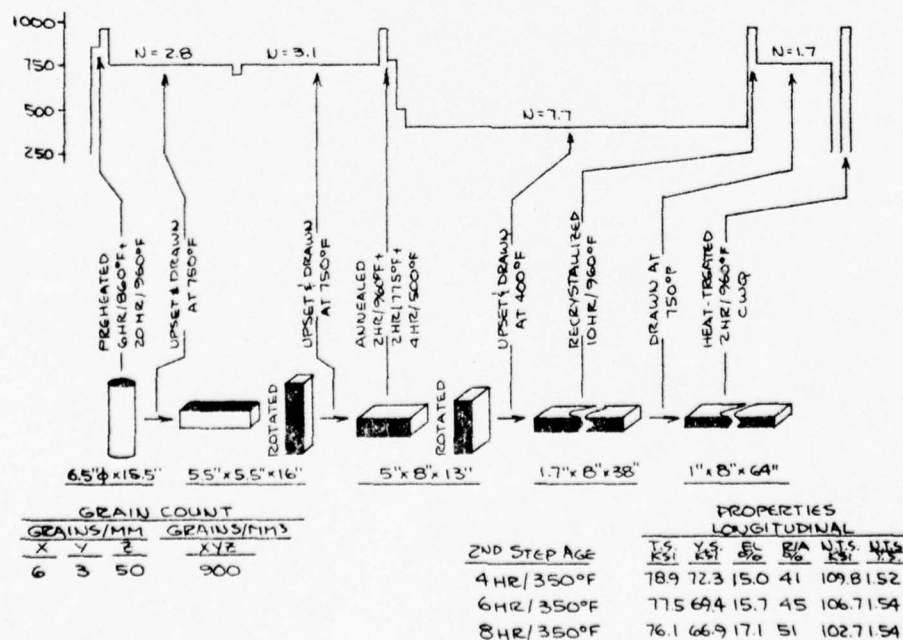
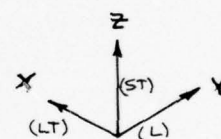
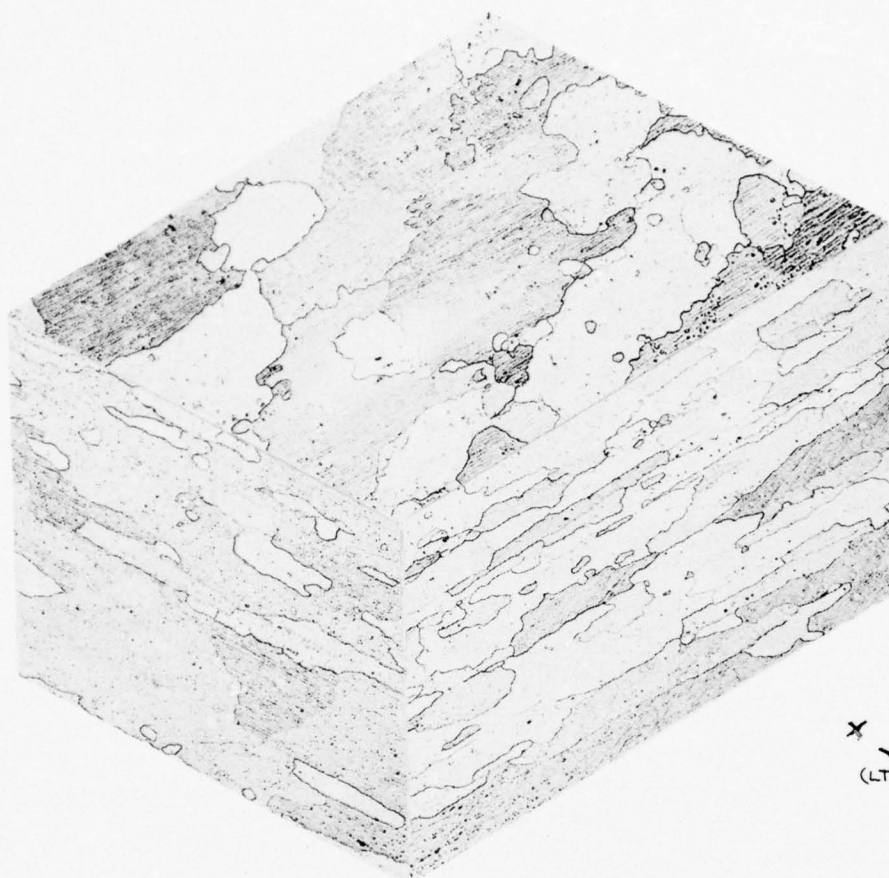


Figure 20. Microstructure, Properties, and Forging Practice for 1-Inch-Thick 7475-T7X Hand Forging S-426669-19.



MAG 100X
1.00" THICK 7475-T7X HAND FORGING

KELLERS ETC H

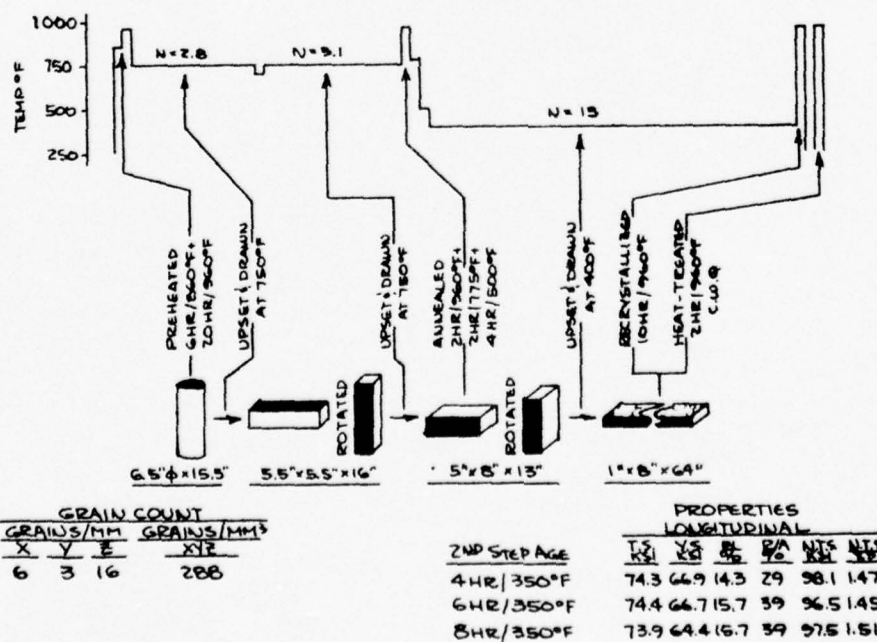
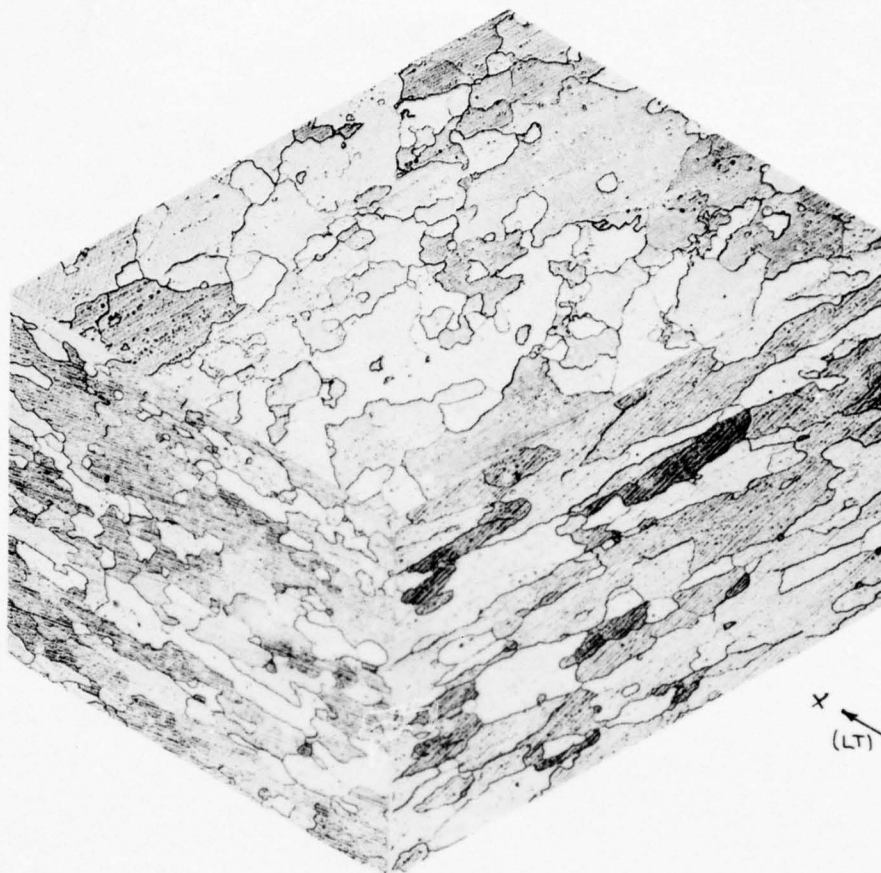


Figure 21. Microstructure, Properties, and Forging Practice for 1-Inch-Thick 7475-T7X Hand Forging S-426669-20.



MAG 100X

KELLER'S ETCH

2.00" THICK 7475-T7X HAND FORGING

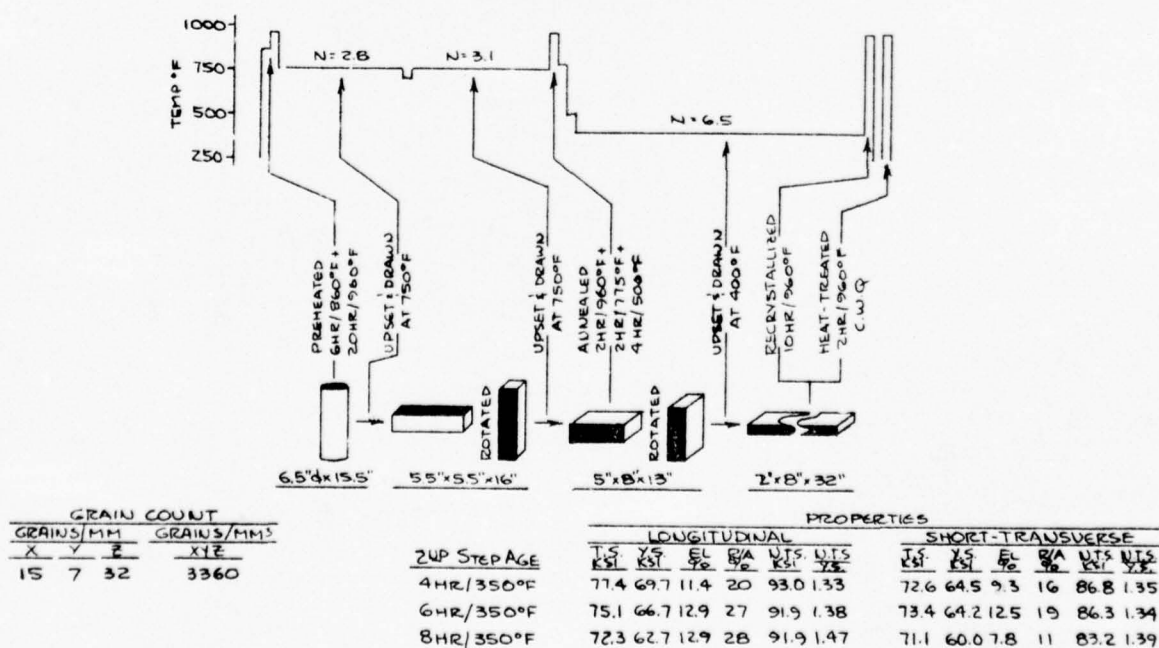
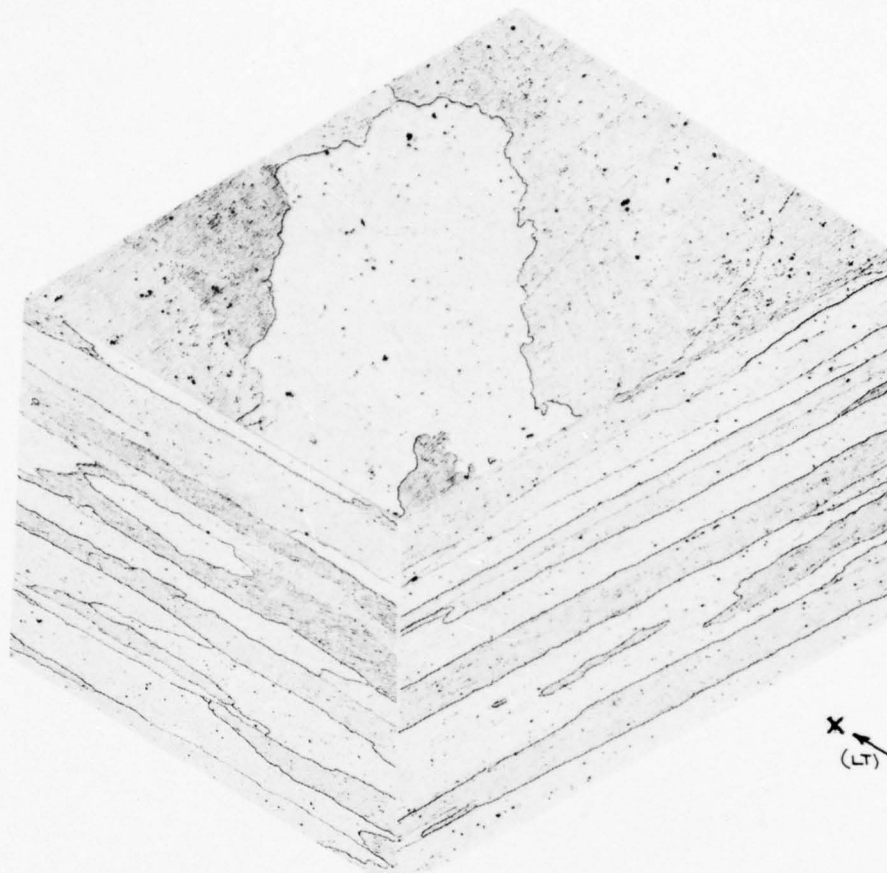


Figure 22. Microstructure, Properties, and Forging Practice for 2-Inch-Thick 7475-T7X Hand Forging S-426669-21.



MAG 100X

100" THICK 7475-T7X HAND FORGING

KELLER'S ETCH

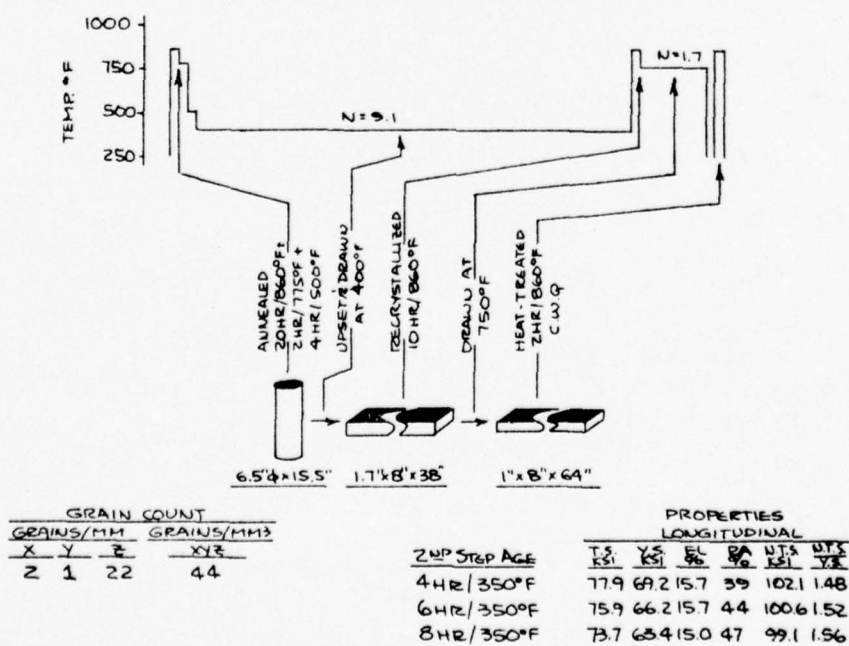
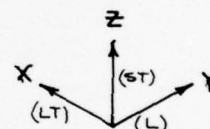
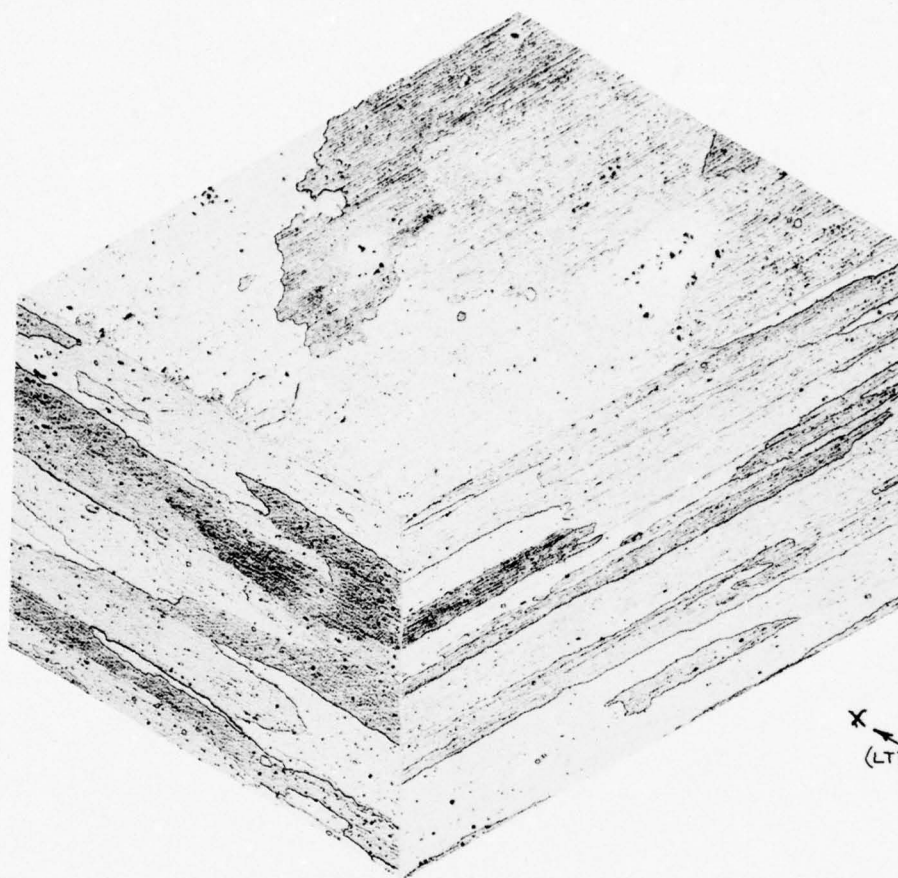
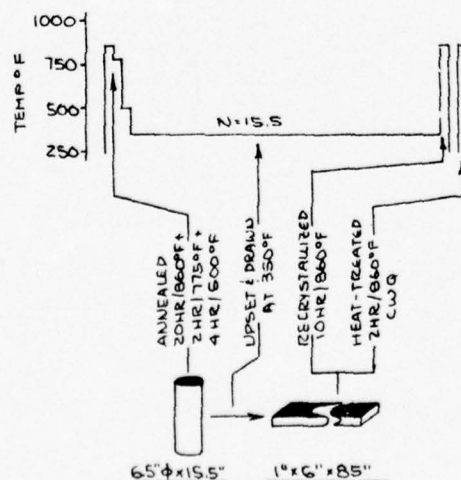


Figure 23. Microstructure, Properties, and Forging Practice for 1-Inch-Thick 7475-T7X Hand Forging S-426669-22.



MAG 100X
1.00" THICK 7475-T7X HAND FORGING

KELLER'S ETCH



GRAIN COUNT			
GRAINS/MM		GRAINS/MM ²	
X	Y	Z	XVZ
3	2	30	180

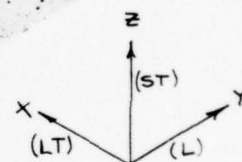
2ND STEP AGE

4HR/350°F
6HR/350°F
8HR/350°F

PROPERTIES LONGITUDINAL

T.S.	Y.S.	EL.	R _m	UTS	UTS
ksi	ksi	%	ksi	ksi	ksi
73.3	64.9	15.7	38	97.5	1.50
74.1	64.1	15.7	41	102.1	1.59
71.1	60.4	15.7	44	98.6	1.63

Figure 24. Microstructure, Properties, and Forging Practice for 1-Inch-Thick 7475-T7X Hand Forging S-426669-23.



MAG 100X
1.00" THICK 7475-T7X HAND FORGING

KELLER'S ETCH

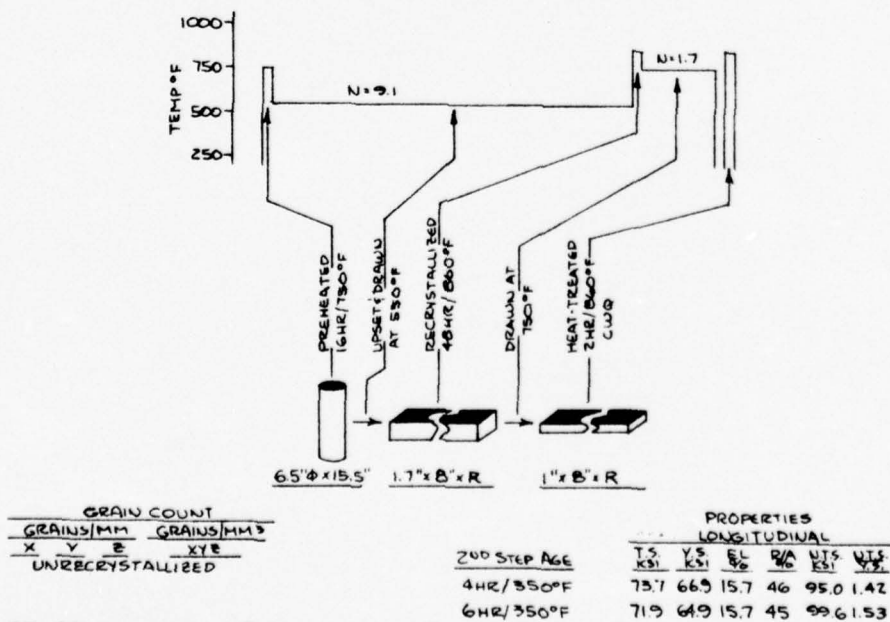
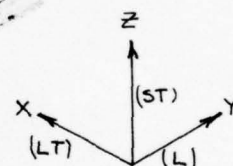
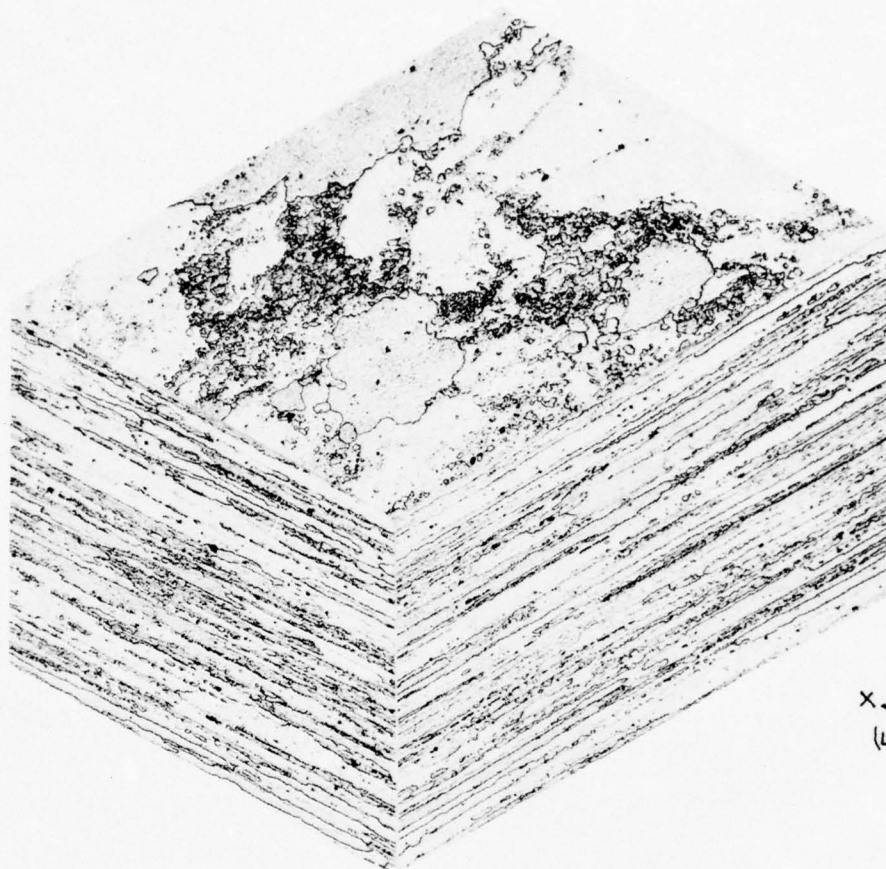
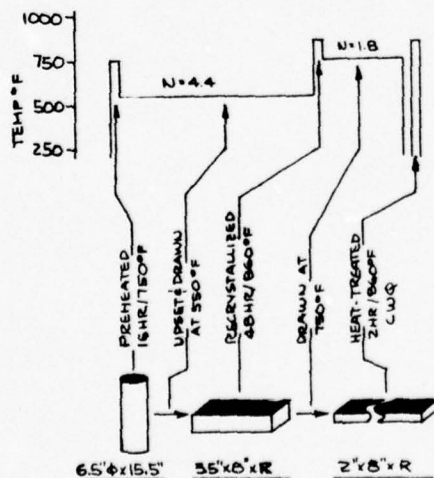


Figure 25. Microstructure, Properties, and Forging Practice for 1-Inch-Thick 7475-T7X Hand Forging S-437666-26A.



MAG 100X
2.00" THICK 7475-T7X HAND FORGING

KELLER'S ETCH

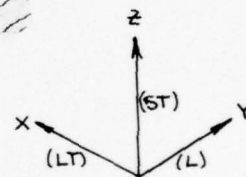
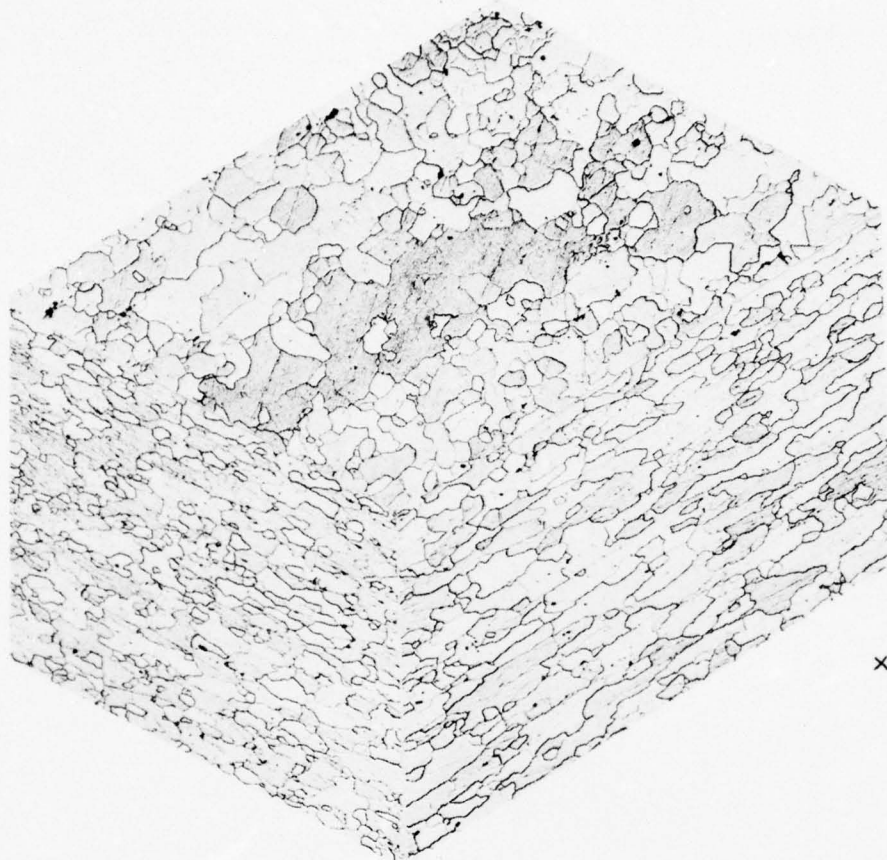


GRAIN COUNT			
GRAINS/MM		GRAINS/MM ²	
X	Y	Z	XYZ
UNRECRYSTALLIZED			

2ND STEP AGE
4HR/350°F
6HR/350°F
8HR/350°F

PROPERTIES							
LONGITUDINAL						SHORT-TRANSVERSE	
T ₃	Y ₃	E ₃	S ₃	NTS	NTS	T ₃	Y ₃
KSI	KSI	KSI	%	KSI	KSI	KSI	KSI
745	67.4	15.7	48	98.6	1.46	71.8	67.0
71.9	63.7	15.7	48	96.2	1.51	72.3	67.2
70.3	61.1	17.1	50	95.5	1.56	72.0	62.5

Figure 26. Microstructure, Properties, and Forging Practice for 2-Inch-Thick 7475-T7X Hand Forging S-437666-26B.



MAG 100X
1.00" THICK 7475-T7X HAND FORGING

KELLER'S ETCH

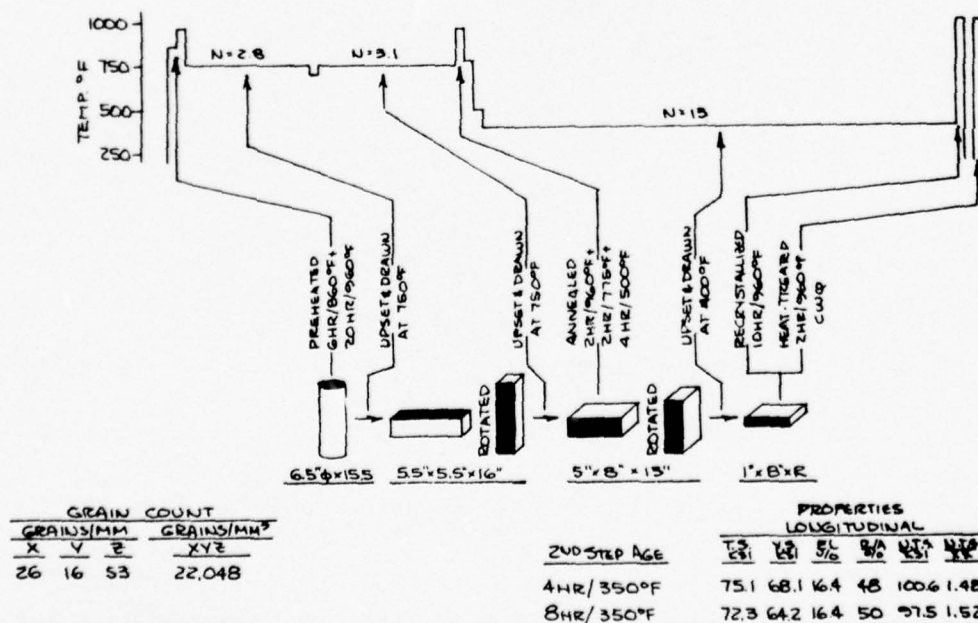
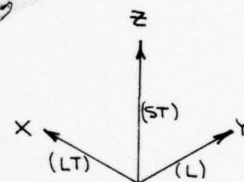
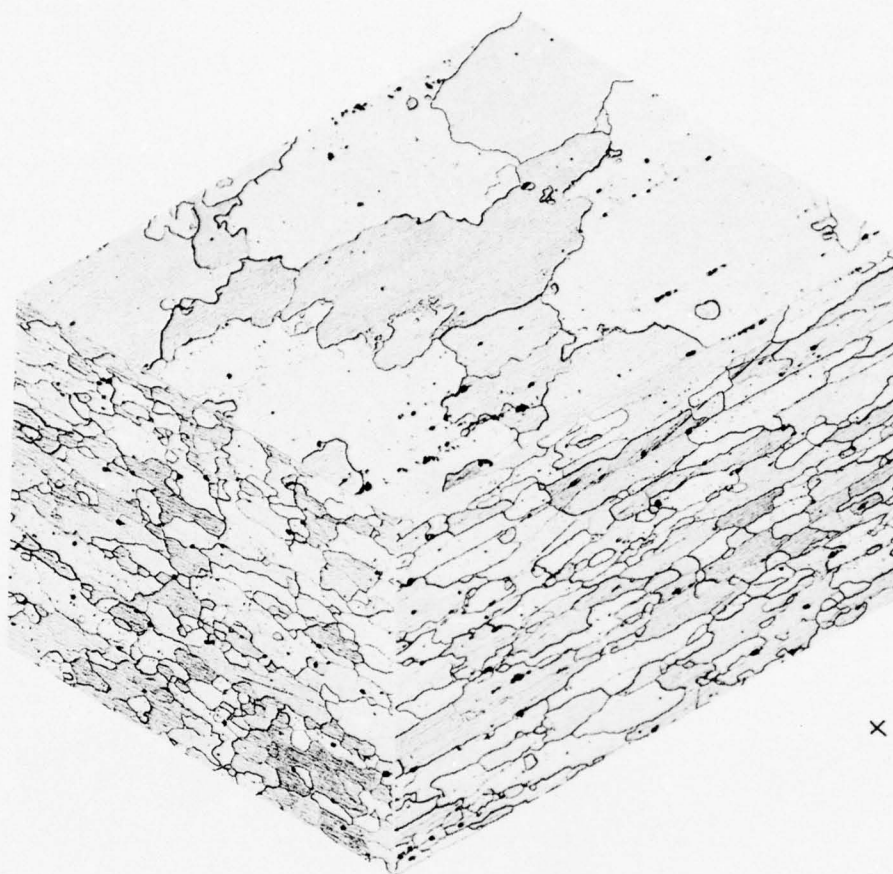


Figure 27. Microstructure, Properties, and Forging Practice for 1-Inch-Thick 7475-T7X Hand Forging S-437666-27A.



MAG 100X
1.5" THICK 7475-T7X HAND FORGING

KELLER'S ETCH

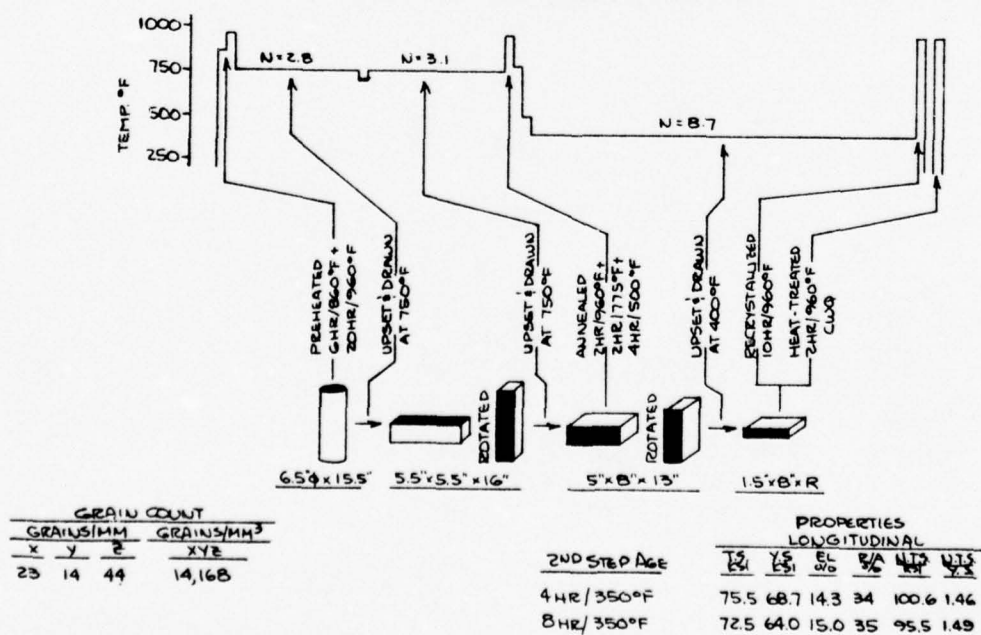
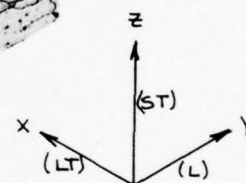
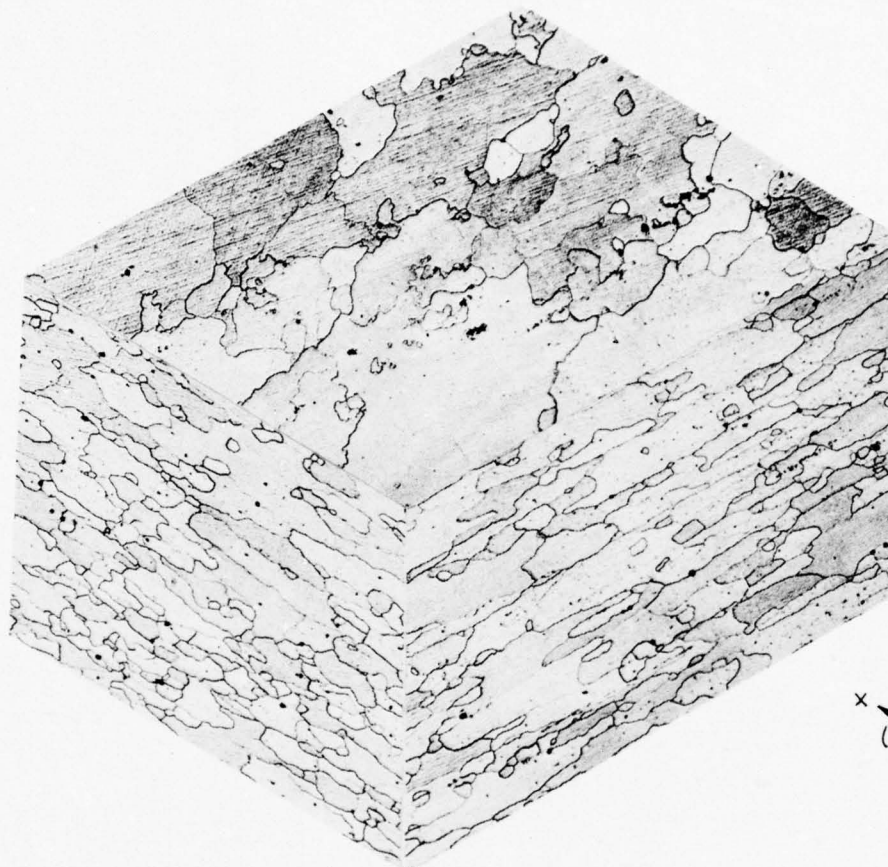


Figure 28. Microstructure, Properties, and Forging Practice for 1.5-Inch-Thick 7475-T7X Hand Forging S-437666-27B.



MAG 100X

KELLER'S ETCH

1.75" THICK 7475-T7X HAND FORGING

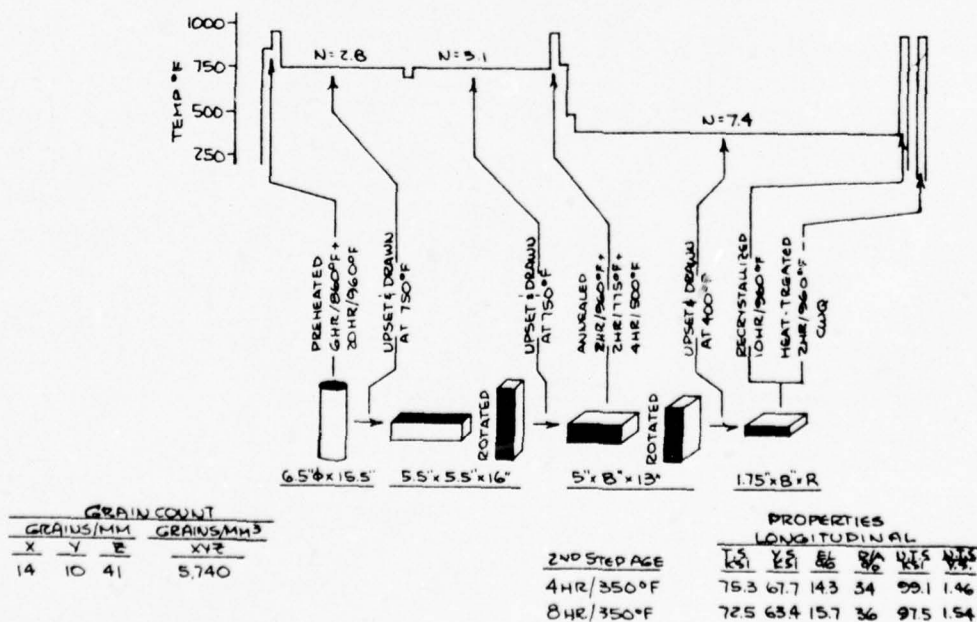
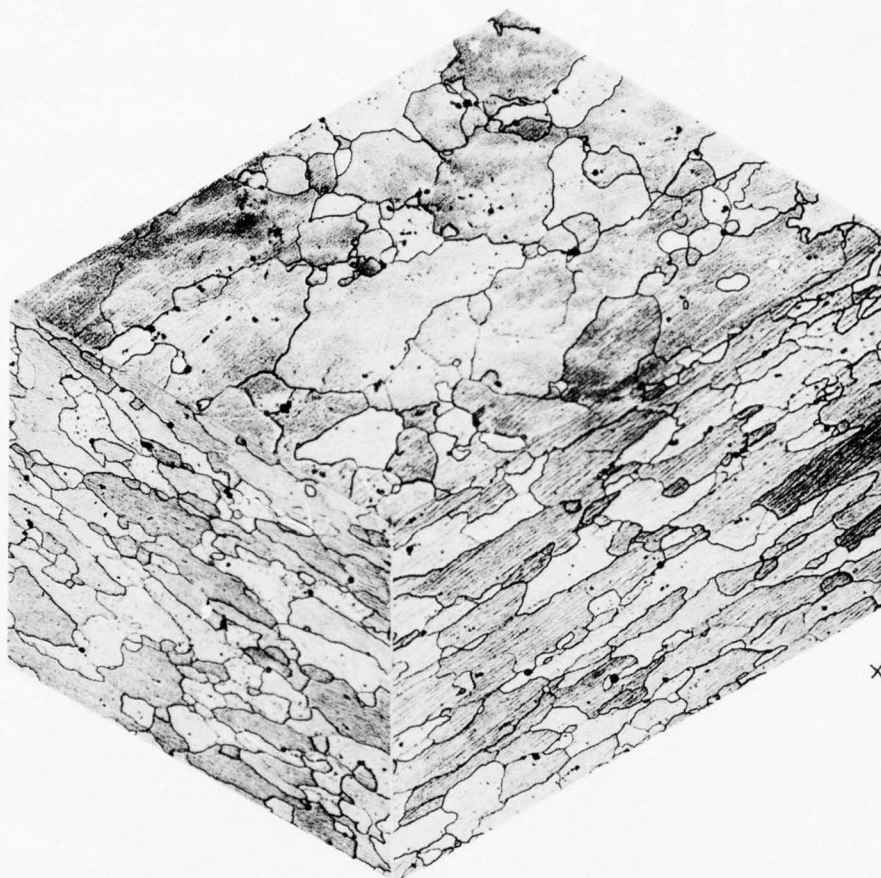
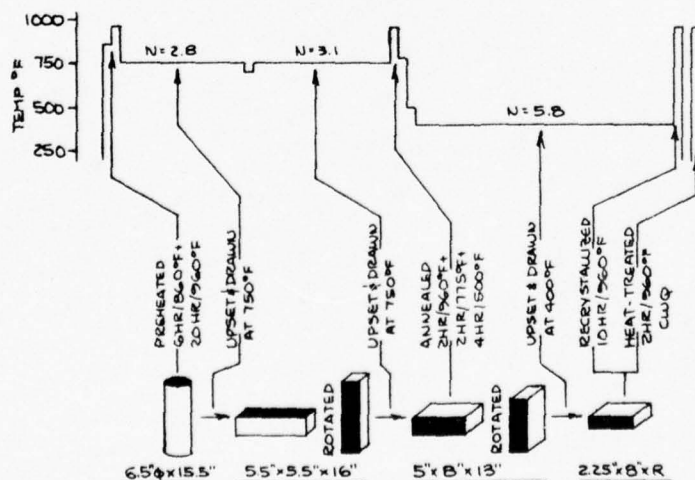


Figure 29. Microstructure, Properties, and Forging Practice for 1.75-Inch-Thick 7475-T7X Hand Forging S-437666-27C.



MAG 100X
2.25" THICK 7475-T7X HAND FORGING

KELLER'S ETCH



GRAIN COUNT			
GRAINS/MM			GRAINS/MM ²
X	Y	Z	XYZ
17	10	29	4.930

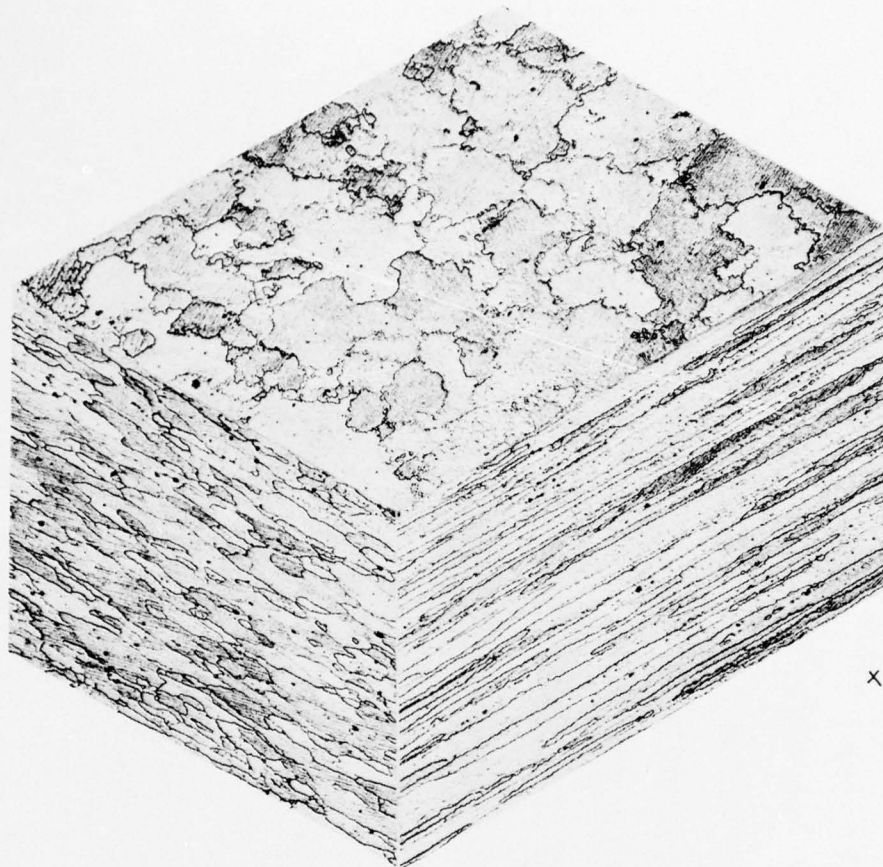
2ND STEP AGE

4 HR/350°F	75.7	68.5	14.3	32	94.5	1.38
8 HR/350°F	72.1	63.9	14.3	27	94.0	1.47

PROPERTIES

LONGITUDINAL							SHORT-TRANSVERSE						
T.S.	Y.S.	EL.	R/A	UTS	UTS	YS	T.S.	Y.S.	EL.	R/A	UTS	UTS	YS
KS	KS	%	%	KS	KS	KS	KS	KS	%	%	KS	KS	KS
75.7	68.5	14.3	32	94.5	1.38	74.9	67.2	12.5	23	81.7	1.21		
72.1	63.9	14.3	27	94.0	1.47	71.5	62.7	10.9	25	86.8	1.39		

Figure 31. Microstructure, Properties, and Forging Practice for 2.25-Inch-Thick 7475-T7X Hand Forging S-437666-27E.



MAG 100X
1.00" THICK 7475-T7X HAND FORGING

KELLER'S ETCH

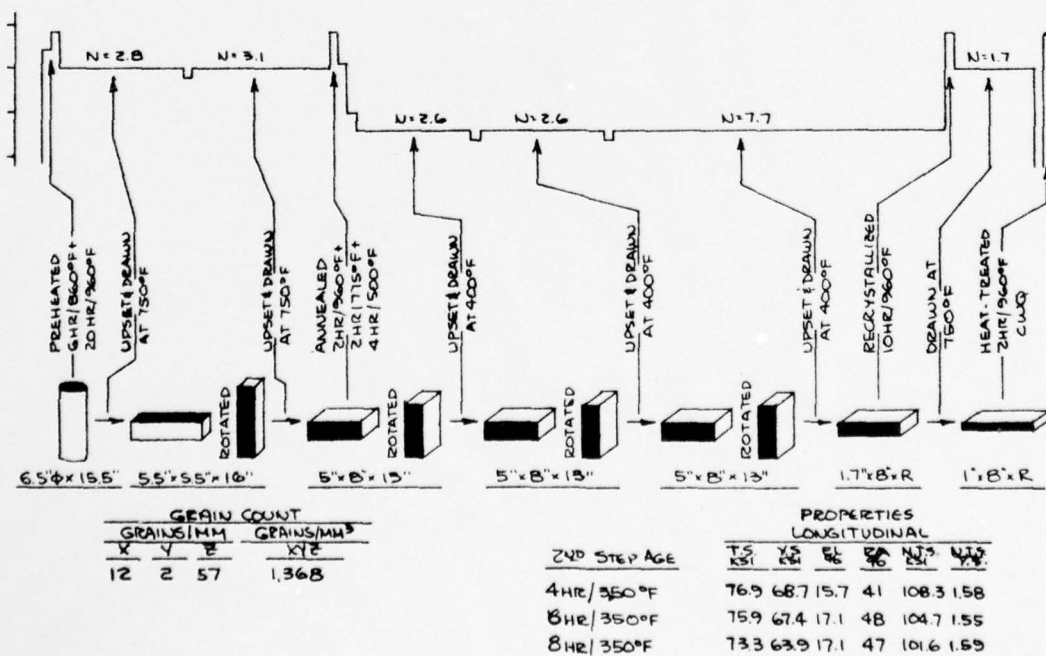
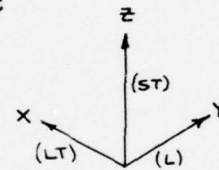
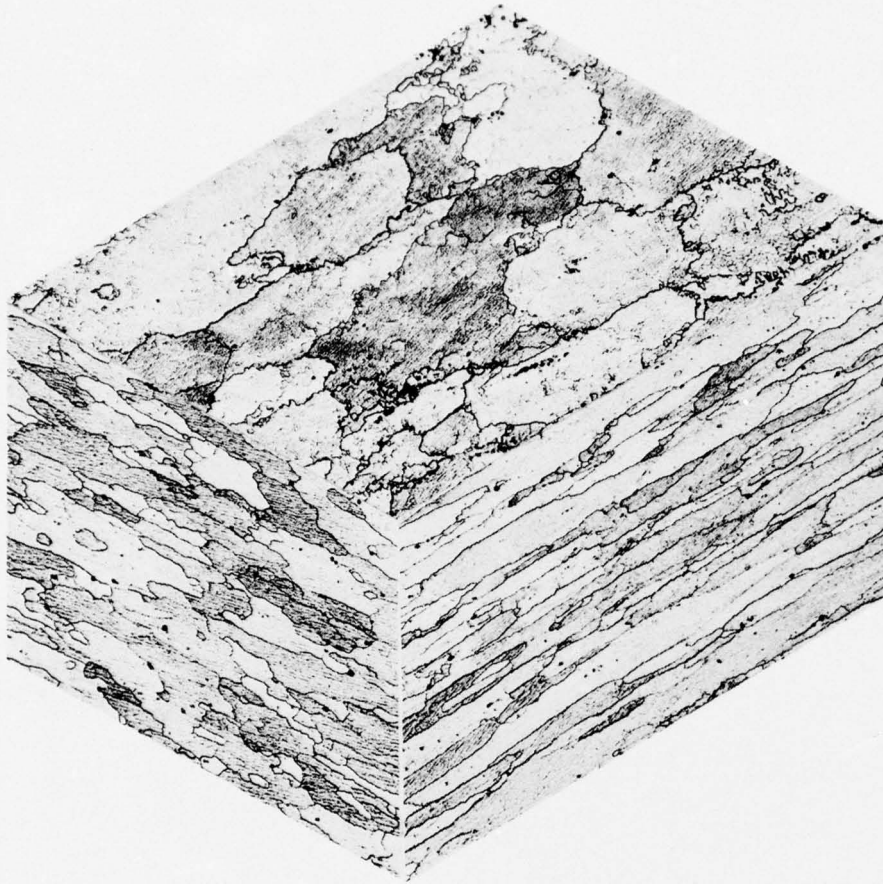


Figure 32. Microstructure, Properties, and Forging Practice for 1-Inch-Thick 7475-T7X Hand Forging S-437666-28A.



MAG 100X
200" THICK 7475-T7X HAND FORGING

KELLER'S ETCH

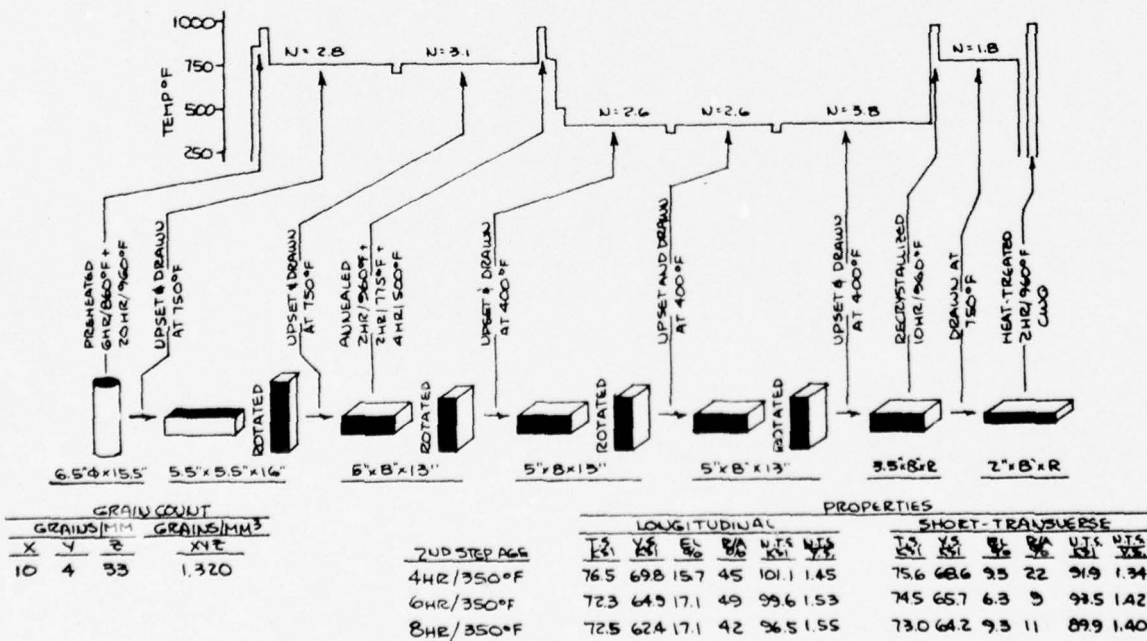


Figure 33. Microstructure, Properties, and Forging Practice for 2-Inch-Thick 7475-T7X Hand Forging S-437666-28B.

TABLE 6. FORGING PRACTICES USED TO FABRICATE 1- TO 1.75-INCH-THICK 7475-T7X HAND FORGINGS IN PHASE III

Final Forging				6.5 ϕ 15.5-In. Ingot Section				Forged Billet				Recrystallization		Forging by Solution-Drawing at 750°F, Temperature Reduction, (°F) N
S.No.	Size (in.)	Grain Count, G/mm			Thermal Treatment	Forging Operation			Size Thermal (in.) Treatment	Forging Operation		Size Thermal Treatment (in.)		
		X	Y	Z		Temp (°F)	Type	Reduction, N		Temp (°F)	Type		Reduction, N	
437666-26A	1x8xR	Unrecry			D	550	Upset & draw	9.1	→ Upset & draw 7.4 1.7x8xR 48 hr/860°F				1.7	2 hr/860
437666-27C	1.75x8xR	14	10	41	A	750	Upset & draw	2.8	5x8x13	A	400	Upset & draw 8.7 1.75x8xR 10 hr/960°F	None	2 hr/960
						750	Upset & draw	3.1						
437666-27D	1.5x8xR	23	14	44	A	750	Upset & draw	2.8	5x8x13	A	400	Upset & draw 13 1.5x8xR 10 hr/960°F	None	2 hr/960
						750	Upset & draw	3.1						
437666-27E	1x8xR	26	16	53	A	750	Upset & draw	2.8	5x8x13	A	400	Upset & draw 2.6 1x8xR 10 hr/960°F	None	2 hr/960
						750	Upset & draw	3.1						
437666-28A	1x8xR	12	2	57	A	750	Upset & draw	2.8	5x8x13	A	400	Upset & draw 2.6 1.7x8xR 10 hr/960°F	None	2 hr/960
						750	Upset & draw	3.1						

NOTES:

- Ingot thermal treatments: A heated 6 hours at 860°F plus 20 hours at 960°F; D heated 16 hours at 750°F.
- Forged-billet thermal treatments: A heated 2 hours at 960°F, cooled to 775°F at 50°F/hour, soaked 2 hours at 775°F, cooled to 500°F at 50°F/hour, and soaked at least 4 hours at 500°F.
- All thermal treatments carried out in circulating-air furnaces.

NOTES: 1. Ingot thermal treatments: A heated 6 hours at 860°F plus 20 hours at 960°F; D heated 16 hours at 750°F.

2. Forged-billet thermal treatments: A heated 2 hours at 960°F, cooled to 775°F, soaked 2 hours at 775°F, cooled to 500°F at 50°F/hour, and soaked at least 4 hours at 500°F.

3. All thermal treatments carried out in circulating-air furnaces.

TABLE 7. FORGING PRACTICES USED TO FABRICATE 2- TO 2.25-INCH-THICK 7475-T7X HAND FORGINGS IN PHASE III

Final Forging				6.5 ϕ x 15.5-In. Ingot Section						Forged Billet						Forging by Solution-Drawing Heat-Treat Temperature Reduction, (°F) N				
S.No.	Size (in.)	Grain Count, G/mm			Thermal Treatment	Forging Operation			Size (in.)	Treatment	Temp (°F)	Forging Operation		Recrystallization		N				
		X	Y	Z		Temp (°F)	Type	Reduction, N				Type	Reduction, N	Size (in.)	Thermal Treatment					
437666-26B	2x8xR	Unrecry			D	550	Upset & draw			4.4	→						3.5x8xR	48 hr/860°F	1.8	2 hr/860
437666-27E	2.25x8xR	17	10	29	A	750	Upset & draw			2.8	5x8x13	A	400	Upset & draw		5.8	2.25x8xR	10 hr/960°F	None	2 hr/960
437666-27D	2x8xR	10	5	25	A	750	Upset & draw			2.8	5x8x13	A	400	Upset & draw		6.5	2x8xR	10 hr/960°F	None	2 hr/960
437666-28B	2x8xR	10	4	33	A	750	Upset & draw			2.8	5x8x13	A	400	Upset & draw		2.6				2 hr/960
						750	Upset & draw			3.1	Upset & draw		2.6	Upset & draw		3.8	3.5x8xR	10 hr/960°F	1.8	2 hr/960

NOTES:

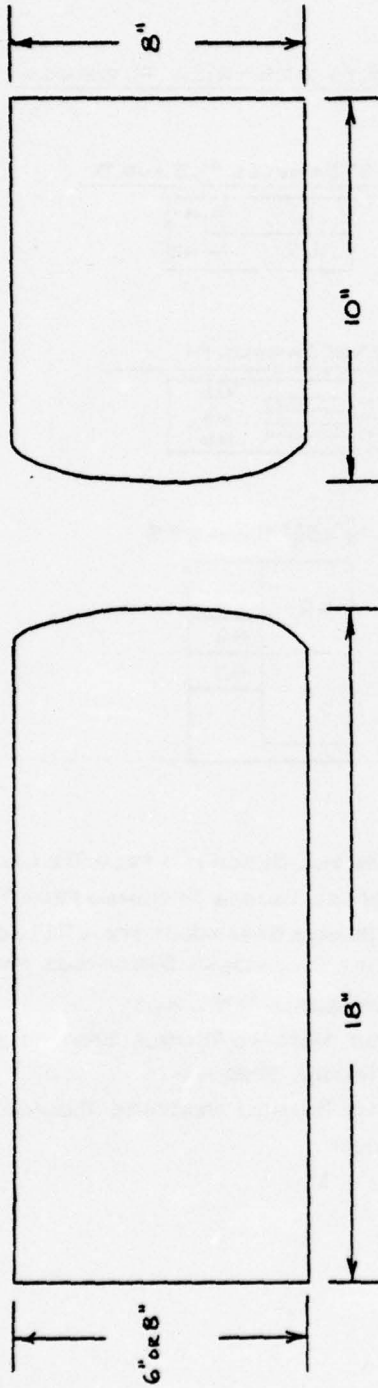
- Ingot thermal treatments: A heated 6 hours at 860°F plus 20 hours at 960°F; D heated 16 hours at 750°F.
- Forged-billet thermal treatments: A heated 2 hours at 960°F, cooled to 775°F; soaked 2 hours at 775°F, cooled to 500°F at 50°F/hour, and soaked at least 4 hours at 500°F.
- All thermal treatments carried out in circulating-air furnaces.

NOTES: 1. Ingot thermal treatments: A heated 6 hours at 860°F plus 20 hours at 960°F; D heated 16 hours at 750°F.
2. Forged-billet thermal treatments: A heated 2 hours at 960°F, cooled to 775°F at 50°F/hour, soaked 2 hours at 775°F, cooled to 500°F at 50°F/hour, and soaked at least 4 hours at 500°F.
3. All thermal treatments carried out in circulating-air furnaces.

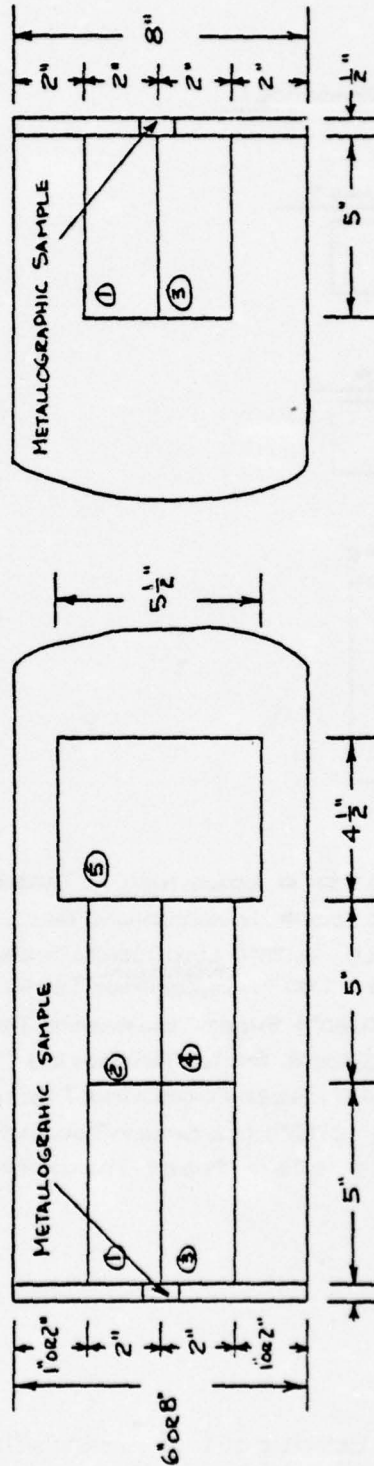
SECTIONS OF 1.00" TO 2.25" THICK 7475 HAND FORGINGS SOLUTION HEAT-TREATED, COLD WATER QUENCHED AND
AGED 24 HR AT 250°F 4 DAYS AFTER QUENCHING

ALL FORGINGS EXCEPT S-437666-27A THRU -27E

FORGINGS S-437666-27A THRU -27E



SECTIONING OF 7475-T6 HAND FORGINGS FOR ADDITIONAL SECOND STEP AGING

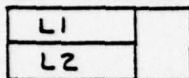


2" x 5" SAMPLE #1 SECOND STEP AGING 4 HR AT 350°F
2" x 5" SAMPLE #2 SECOND STEP AGING 6 HR AT 350°F
2" x 5" SAMPLE #3 & 4 SECOND STEP AGING 8 HR AT 350°F
4 1/2" x 5 1/2" SAMPLE #5 SECOND STEP AGING 8 HR AT 350°F

Figure 34. Solution Heat-Treatment, Quenching, and Artificial Aging of 1- to 2.25-Inch-Thick 7475 Hand Forging.

1.00" TO 1.75" THICK FORGINGS

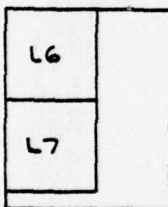
2"x5" SAMPLES #1, 2 AND 3



2"x5" SAMPLE #4

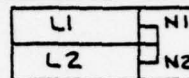


4 1/2" x 5 1/2" SAMPLE #5

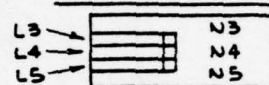


2.00" TO 2.25" THICK FORGINGS

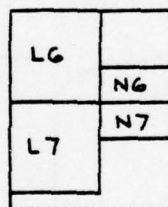
2"x5" SAMPLES #1, 2 AND 3



2"x5" SAMPLE #4



4 1/2" x 5 1/2" SAMPLE #5



- SPECIMEN L1 0.357" ϕ LONGITUDINAL TAPERED SEAT TENSILE SPECIMEN FROM T/2 LOCATION
 SPECIMEN L2 0.500" ϕ LONGITUDINAL TAPERED SEAT NOTCHED TENSILE SPECIMEN FROM T/2 LOCATION
 SPECIMENS L3, L4, L5 0.125" ϕ LONGITUDINAL THREADED END TENSILE SPECIMENS FROM T/2 LOCATION
 SPECIMENS L6, L7 1.00" THICK, LONGITUDINAL COMPACT TENSION FRACTURE TOUGHNESS SPECIMENS FROM T/2 LOCATION
 SPECIMEN N1 0.160" ϕ SHORT-TRANSVERSE TAPERED SEAT TENSILE SPECIMEN
 SPECIMEN N2 0.500" ϕ SHORT-TRANSVERSE TAPERED SEAT NOTCHED TENSILE SPECIMEN
 SPECIMENS N3, N4, N5 SHORT-TRANSVERSE THREADED END TENSILE SPECIMENS
 SPECIMENS N6, N7 0.75" THICK SHORT-TRANSVERSE COMPACT TENSION FRACTURE TOUGHNESS SPECIMENS
 SPECIMENS C1, C2, C3 0.75" ϕ SHORT-TRANSVERSE C-RINGS.

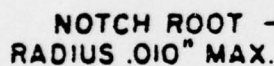
Figure 35. Sampling of 1- to 2.25-Inch-Thick 7475-T7X Hand Forgings for Mechanical-Property and Corrosion Tests.

Technical drawing of a mechanical part, likely a shaft or pin, showing dimensions and angles. The drawing includes a side view and a cross-sectional view.

Dimensions:

- Overall length: $4\frac{3}{4}$ "
- Left shoulder width: $\frac{1}{2}$ "
- Left shoulder height: $\frac{5}{16}$ "
- Left shoulder radius: 62°
- Left shaft diameter: 0.353 " Diam
- Left shaft length: $1\frac{9}{16}$ "
- Left shaft radius: 60°
- Central shaft diameter: 0.500 " Diam
- Central shaft length: $1\frac{9}{16}$ "
- Right shoulder height: $\frac{5}{16}$ "
- Right shoulder radius: 60°
- Right shaft diameter: $\frac{3}{4}$ " Diam
- Right shaft length: $\frac{1}{2}$ "

Figure 36. Sharply Notched, 1/2-Inch-Diameter Notch-Tensile Specimen (Tapered Seat).



D. = 0.58

TABLE 8. PROPERTIES OF 1-INCH-THICK RECRYSTALLIZED PLUS HOT-WORKED 7475-T7X HAND FORGINGS

S.No.	Thickness (in.)	Solution- Heat-Treat Temperature (°F)	2nd-Step Aging	Longitudinal Mechanical Properties						
				UTS ¹ (ksi)	YS (ksi)	El (%)	Reduction in Area (%)	NTS ² (ksi)	NTS/YS	K _Q ³ (ksi√in.)
426669-11	1.00	960	4 hr/350°F	78.7	72.7	17.1	47	109.3	1.50	
			6 hr/350°F	74.3	66.9	17.9	57	108.3	1.62	
			8 hr/350°F	75.1	66.4	16.4	46	103.7	1.56	54.0
			Avg			17.1	50		1.56	
426669-12	1.00	960	4 hr/350°F	78.5	71.9	16.4	51	107.3	1.49	
			6 hr/350°F	76.7	68.7	17.9	51	107.8	1.57	
			8 hr/350°F	77.7	69.7	17.9	53	107.3	1.54	42.6
			Avg			17.4	52		1.53	
426669-13	1.00	860	4 hr/350°F	76.1	67.7	15.0	42	103.2	1.52	
			6 hr/350°F	73.9	63.7	15.7	42	100.6	1.58	
			8 hr/350°F	73.1	62.4	15.7	41	100.6	1.52	
			Avg			15.5	42		1.54	
426669-19	1.00	960	4 hr/350°F	78.9	72.3	15.0	41	109.8	1.52	
			6 hr/350°F	77.5	69.4	15.7	45	106.7	1.54	
			8 hr/350°F	76.1	66.9	17.1	51	102.7	1.54	49.8
			Avg			15.9	46		1.53	
426669-22	1.00	960	4 hr/350°F	77.9	69.2	15.7	39	102.1	1.48	
			6 hr/350°F	75.9	66.2	15.7	44	100.6	1.52	
			8 hr/350°F	73.7	63.4	15.0	47	99.1	1.56	50.4
			Avg			15.5	43		1.52	
437666-28A	1.00	960	4 hr/350°F	76.9	68.7	15.7	41	108.3	1.58	
			6 hr/350°F	75.9	67.4	17.1	48	104.7	1.55	
			8 hr/350°F	73.3	63.9	17.1	47	101.6	1.59	51.4
			Avg			16.6	45		1.57	

NOTES: 1. Single 0.357-inch ϕ tapered-seat longitudinal tensile specimens and 0.160-inch ϕ tapered-seat short-transverse tensile specimens.
2. Single 0.500-inch ϕ tapered-seat longitudinal and short-transverse notched tensile specimens.
3. Duplicate 1.00-inch-thick longitudinal and 0.75-inch-thick short-transverse compact-tension fracture-toughness tests.
4. Forgings solution-heat-treated, cold-water-quenched, and artificially aged 24 hours at 250°F plus indicated 2nd-step aging at least 4 days after quenching.

TABLE 9. PROPERTIES OF 1- TO 1.75-INCH-THICK RECRYSTALLIZED 7475-T7X HAND FORGINGS

S.No.	Thickness (in.)	Solution- Heat-Treat Temperature (°F)	2nd-Step Aging	Longitudinal Mechanical Properties						
				UTS ¹ (ksi)	YS (ksi)	El (%)	Reduction in Area (%)	NTS ² (ksi)	NTS/YS	K _Q ³ (ksi√in.)
426669-8	1.00	960	4 hr/350°F	77.1	70.2	15.7	42	107.8	1.54	—
			6 hr/350°F	74.7	68.4	16.4	43	105.2	1.54	—
			8 hr/350°F	75.9	64.9	15.0	37	105.2	1.62	—
			Avg			15.7	41		1.57	
426669-9	1.00	960	4 hr/350°F	79.3	72.4	14.3	36	107.3	1.48	—
			6 hr/350°F	76.7	69.2	16.4	31	106.7	1.54	—
			8 hr/350°F	75.3	66.7	15.0	39	105.7	1.58	—
			Avg			15.2	35		1.53	
426669-10	1.00	960	4 hr/350°F	76.5	70.2	15.7	43	106.2	1.51	—
			6 hr/350°F	74.3	68.2	15.0	47	103.7	1.52	—
			8 hr/350°F	74.5	65.9	15.0	38	104.2	1.58	—
			Avg			15.2	43		1.54	
426669-17	1.00	860	4 hr/350°F	76.1	67.4	14.3	38	102.7	1.52	—
			6 hr/350°F	75.9	65.2	17.1	43	99.6	1.53	—
			8 hr/350°F	73.1	62.9	13.6	40	99.3	1.58	—
			Avg			15.0	40		1.54	
426669-18	1.00	960	4 hr/350°F	77.9	71.2	15.7	38	104.7	1.47	—
			6 hr/350°F	76.1	68.4	15.7	38	103.2	1.51	—
			8 hr/350°F	73.5	65.4	15.7	45	102.7	1.57	50.1
			Avg			15.7	40		1.52	
426669-20	1.00	960	4 hr/350°F	74.3	66.9	14.3	29	98.1	1.47	—
			6 hr/350°F	74.4	66.7	15.7	39	96.5	1.45	—
			8 hr/350°F	73.9	64.4	15.7	39	97.5	1.51	—
			Avg			15.2	36		1.48	
426669-23	1.00	860	4 hr/350°F	73.3	64.9	15.7	38	97.5	1.50	—
			6 hr/350°F	74.1	64.1	15.7	41	102.1	1.59	—
			8 hr/350°F	71.1	60.4	15.7	44	98.6	1.63	—
			Avg			15.7	41		1.57	
437666-27A	1.00	960	4 hr/350°F	75.1	68.1	16.4	48	100.6	1.48	—
			8 hr/350°F	72.3	64.2	16.4	50	97.5	1.52	—
			Avg			16.4	49		1.50	
437666-27B	1.50	960	4 hr/350°F	75.5	68.7	14.3	34	100.6	1.46	—
			8 hr/350°F	72.5	64.0	15.0	35	95.5	1.49	—
			Avg			14.6	35		1.48	
437666-27C	1.75	960	4 hr/350°F	75.3	67.7	14.3	34	99.1	1.46	—
			8 hr/350°F	72.5	63.4	15.7	36	97.5	1.54	—
			Avg			15.0	35		1.50	

NOTES:

1. Single 0.357-inch ϕ tapered-seat longitudinal tensile specimens and 0.160-inch ϕ tapered-seat short-transverse tensile specimens.
2. Single 0.500-inch ϕ tapered-seat longitudinal and short-transverse notched tensile specimens.
3. Duplicate 1.00-inch-thick longitudinal and 0.75-inch-thick short-transverse compact-tension fracture-toughness tests.
4. Forgings solution-heat-treated, cold-water-quenched, and artificially aged 24 hours at 250°F plus indicated 2nd-step aging at least 4 days after quenching.

TABLE 10. PROPERTIES OF 1-INCH-THICK UNRECRYSTALLIZED 7475-T7X HAND FORGINGS

S.No.	Thickness (in.)	Solution- Heat-Treat Temperature (°F)	2nd-Step Aging	Longitudinal Mechanical Properties				
				UTS ¹ (ksi)	YS (ksi)	El (%)	Reduction in Area (%)	NTS ² (ksi) NTS/YS
426669-14	1.00	960	4 hr/350°F	78.9	72.4	15.7	48	106.7 1.47
			6 hr/350°F	75.7	67.9	16.4	50	103.2 1.52
			8 hr/350°F	74.7	67.2	17.9	50	104.2 1.55
437666-26A	1.00	860	4 hr/350°F	73.7	66.9	15.7	46	95.0 1.42
			6 hr/350°F	71.9	64.9	15.7	45	99.6 1.53
			8 hr/350°F	72.1	61.9	15.7	44	101.6 1.64

NOTES: 1. Single 0.357-inch ϕ tapered-seat longitudinal tensile specimens and 0.160-inch ϕ tapered-seat short-transverse tensile specimens.
2. Single 0.500-inch ϕ tapered-seat longitudinal and short-transverse notched tensile specimens.
3. Forgings solution-heat-treated, cold-water-quenched, and artificially aged 24 hours at 250°F plus indicated 2nd-step aging at least 4 days after quenching.

TABLE 11. PROPERTIES OF 2-INCH-THICK RECRYSTALLIZED PLUS HOT-WORKED 7475-T7X HAND FORGINGS

S.No.	Thickness (in.)	Solution - Heat-Treat Temperature (°F)	Mechanical Properties												
			Longitudinal					Short-Transverse							
			El (%)	RA (%)	NTS ² (ksi)	K _Q ³ (ksi√in.)	UTS ¹ (ksi)	YS (ksi)	El (%)	RA (%)	NTS ² (ksi)	NTS/YS	K _Q ³ (ksi√in.)		
426669-1	2.00	960													
426669-5	2.00	960													
426669-6	2.00	960													
437666-28B	2.00	960													

NOTES: 1. Single 0.357-inch ϕ tapered-seat longitudinal tensile specimens and 0.160-inch ϕ tapered-seat short-transverse tensile specimens.

2. Single 0.500-inch ϕ tapered-seat longitudinal and short-transverse notched tensile specimens.

3. Duplicate 1.00-inch-thick longitudinal and 0.75-inch-thick short-transverse compact-tension fracture-toughness tests.

4. Forgings solution-heat-treated, cold-water-quenched, and artificially aged 24 hours to 250°F plus indicated 2nd-step aging at least 4 days after quenching.

TABLE 12. PROPERTIES OF 2- TO 2.25-INCH-THICK RECRYSTALLIZED 7475-T7X HAND FORGINGS

S.No.	Thickness (in.)	Solution - Heat-Treat Temperature (°F)	Mechanical Properties													
			Longitudinal							Short-Transverse						
			UTS ¹ (ksi)	YS (ksi)	El (%)	RA (%)	NTS ² (ksi)	NTS/YS (ksi √in.)	K _Q ³ (ksi √in.)	UTS ¹ (ksi)	YS (ksi)	El (%)	RA (%)	NTS ² (ksi)	NTS/YS (ksi √in.)	K _Q ³ (ksi √in.)
426669-2	2.00	960	78.3	70.7	14.3	19	103.2	1.46	—	79.1	68.7	6.2	6	89.9	1.31	—
			75.9	67.9	12.9	24	98.6	1.45	—	78.4	66.4	9.4	11	91.9	1.38	—
			74.9	65.4	13.6	30	99.1	1.51	—	73.1	65.7	4.7	6	93.0	1.42	—
			Avg		13.6	24		1.47				6.8	8		1.37	
426669-3	2.00	960	77.3	70.9	14.3	27	98.6	1.39	—	74.6	67.9	4.7	7	90.4	1.33	—
			75.1	67.4	14.3	30	98.6	1.46	—	73.6	63.1	7.8	7	99.6	1.57	—
			73.9	65.9	13.6	30	99.6	1.51	—	73.1	62.7	7.8	11	95.0	1.52	—
			Avg		14.1	29		1.45				6.8	8		1.47	
426669-16	2.00	960	76.1	68.7	12.6	24	100.6	1.46	—	75.1	66.4	7.8	10	84.8	1.28	—
			74.9	65.9	12.1	23	99.6	1.51	—	73.6	61.9	9.4	10	85.8	1.38	—
			72.7	63.2	12.1	25	92.4	1.46	—	73.9	62.3	10.9	7	94.0	1.51	—
			Avg		12.3	24		1.48				9.4	9		1.39	
426669-21	2.00	960	77.4	69.4	11.4	20	93.0	1.33	—	72.6	64.5	9.3	16	86.8	1.35	—
			75.1	66.7	12.9	27	91.9	1.38	—	73.4	64.2	12.5	19	86.3	1.34	—
			72.3	62.7	12.9	28	91.9	1.47	46.6	71.1	60.0	7.8	11	83.2	1.39	44.6
			Avg		12.4	25		1.39				9.9	15		1.36	
437666-27D	2.00	960	74.3	66.7	15.7	35	101.1	1.52	—	74.1	66.0	12.5	24	90.4	1.37	—
			72.5	62.9	15.7	36	93.7	1.49	—	73.9	65.7	12.5	22	91.9	1.40	—
			Avg		15.7	36		1.50				12.5	23		1.38	
437666-27E	2.25	960	75.7	68.5	14.3	32	94.5	1.38	—	74.9	67.2	12.5	23	81.7	1.21	—
			72.1	63.9	14.3	27	94.0	1.47	—	71.5	62.7	10.9	25	86.8	1.39	—
			Avg		14.3	30		1.42				11.7	24		1.30	

- NOTES:
1. Single 0.357-inch ϕ tapered-seat longitudinal tensile specimens and 0.160-inch ϕ tapered-seat short-transverse tensile specimens.
 2. Single 0.500-inch ϕ tapered-seat longitudinal and short-transverse notched tensile specimens.
 3. Duplicate 1.00-inch-thick longitudinal and 0.75-inch-thick short-transverse compact-tension fracture-toughness tests.
 4. Forgings solution-heat-treated, cold-water-quenched, and artificially aged 24 hours at 250°F, plus indicated 2nd-step aging at least 4 days after quenching.

TABLE 13. PROPERTIES OF 2-INCH-THICK UNRECRYSTALLIZED 7475-T7X HAND FORGINGS

S.No.	Thickness (in.)	Solution- Heat-Treat Temperature (°F)	2nd-Step Aging	Mechanical Properties											
				Longitudinal						Short-Transverse					
				UTS ¹ (ksi)	YS (ksi)	El (%)	RA (%)	NTS ² (ksi)	K _Q ³ (ksi √in.)	UTS ¹ (ksi)	YS (ksi)	El (%)	RA (%)	NTS ² (ksi)	K _Q ³ (ksi √in.)
426669-7	2.00	860	4 hr/350°F	73.3	64.9	14.3	33	95.0	1.46	74.1	65.3	7.8	6	91.9	1.41
			6 hr/350°F	70.9	61.2	14.3	32	92.4	1.51	69.7	60.4	12.5	29	91.4	1.51
			8 hr/350°F	70.7	60.4	15.0	29	95.0	1.57	70.6	57.8	10.9	20	85.8	1.48
426669-15	2.00	960	4 hr/350°F	78.7	72.2	12.9	27	101.6	1.41	77.1	70.1	7.8	29	103.2	1.47
			6 hr/350°F	76.7	69.2	15.0	41	103.7	1.50	75.9	67.9	4.7	2	103.7	1.53
			8 hr/350°F	73.1	64.4	17.9	49	99.1	1.54	72.4	64.9	7.8	5	95.5	1.47
437666-26B	2.00	860	4 hr/350°F	74.5	67.4	15.7	48	98.6	1.46	71.8	67.0	3.1	6	93.0	1.39
			6 hr/350°F	71.9	63.7	15.7	48	96.2	1.51	72.3	67.2	3.1	7	88.9	1.32
			8 hr/350°F	70.3	61.1	17.1	50	95.5	1.56	72.0	62.5	6.3	10	88.4	1.41

NOTES: 1. Single 0.357-inch ϕ tapered-seat longitudinal tensile specimens and 0.160-inch ϕ tapered-seat short-transverse tensile specimens.

2. Single 0.500-inch ϕ tapered-seat longitudinal and short-transverse notched tensile specimens.

3. Duplicate 1.00-inch-thick longitudinal and 0.75-inch-thick short-transverse compact-tension fracture-toughness tests.

4. Forgings solution-heat-treated, cold-water-quenched, and artificially aged 24 hours at 250°F plus indicated 2nd-step aging at least 4 days after quenching.

TABLE 14. RESULTS OF ACCELERATED STRESS-CORROSION TESTS ON 1- TO 2-INCH-THICK
7475-T7X HAND FORGINGS (LONGITUDINAL SPECIMENS)

S.No.	Thickness (in.)	Grain Dimensions			Tensile Properties			1/8-In. ϕ Tensile Bars Stressed at 75% YS ¹			
		Thickness (mm)	Width (mm)	Length (mm)	Aspect Ratio	UTS (ksi)	YS (ksi)	El (%)	Spec L3	Spec L4	Spec L5
Recrystallized Plus Hot-Worked											
426669-1	2.00	0.028	1.000	1.000	35.7	74.5	66.4	17.0	OK 84DA	OK 84DA	OK 84DA
437666-28B	2.00	0.030	0.250	0.100	3.3	72.5	62.4	17.0	OK 84DA	OK 84DA	OK 84DA
426669-5	2.00	0.036	1.000	1.000	27.7	74.3	66.9	18.0	OK 84DA	OK 84DA	OK 84DA
426669-6	2.00	0.042	0.500	0.250	6.0	76.7	68.7	17.0	OK 84DA	OK 84DA	OK 84DA
437666-28A	1.00	0.018	0.500	0.083	4.6	75.8	68.0	16.0	OK 84DA	OK 84DA	OK 84DA
426669-19	1.00	0.020	0.333	0.167	8.4	77.9	70.1	14.0	OK 84DA	OK 84DA	OK 84DA
426669-12	1.00	0.023	0.500	0.200	8.7	76.6	66.0	13.0	OK 84DA	OK 84DA	OK 84DA
426669-11	1.00	0.025	0.500	0.333	13.2	78.7	68.6	13.0	OK 84DA	OK 84DA	OK 84DA
426669-22	1.00	0.046	1.000	0.500	10.9	76.0	64.9	17.0	OK 84DA	OK 84DA	OK 84DA
Recrystallized											
426669-21	2.00	0.031	0.143	0.067	2.2	75.1	66.7	13.0	OK 84DA	OK 84DA	OK 84DA
426669-18	1.00	0.040	0.333	0.200	5.0	77.0	67.1	16.0	OK 84DA	OK 84DA	OK 84DA
Unrecrystallized											
426669-15	2.00	—	—	—	—	73.1	64.4	18.0	OK 84DA	OK 84DA	OK 84DA
437666-26B	2.00	—	—	—	—	71.9	63.7	16.0	OK 84DA	OK 84DA	OK 84DA
426669-14	1.00	—	—	—	—	77.8	69.2	13.0	OK 84DA	OK 84DA	OK 84DA
NOTES:											
1. Specimens exposed stressed for 84 days by alternate immersion to 3.5% NaCl solution (Federal Test Method 823).											
2. All forgings artificially aged 24 hours at 250°F plus 8 hours at 350°F.											
3. Specimens from T/2 location.											

TABLE 15. RESULTS OF ACCELERATED STRESS-CORROSION TESTS ON 1- TO 2-INCH-THICK
7475-T7X HAND FORGINGS (SHORT-TRANSVERSE SPECIMENS)

S.No.	Thickness (in.)	Grain Dimensions			Tensile Properties			1/8-In. ϕ Tensile Bars Stressed at 42 ksi			3/4-In. ϕ C-Rings Stressed at 42 ksi			
		Thickness (mm)	Width (mm)	Length (mm)	Aspect Ratio	UTS (ksi)	YS (ksi)	EI (%)	N3	N4	N5	C1	C2	C3
Recrystallized Plus Hot-Worked														
A26669-1	2.00	0.028	1.000	1.000	35.7	76.0	66.6	12.0	OK 84DA	OK 84DA	OK 84DA	-	-	-
437666-28B	2.00	0.030	0.250	0.100	3.3	72.7	64.0	9.0	OK 84DA	OK 84DA	OK 84DA	-	-	-
426669-5	2.00	0.036	1.000	1.000	27.7	75.2	64.3	11.0	OK 84DA	OK 84DA	OK 84DA	-	-	-
426669-6	2.00	0.042	0.500	0.250	6.0	75.4	67.0	9.0	F 68DA	F 84DA	OK 84DA	-	-	-
437666-28A	1.00	0.018	0.500	0.083	4.6	-	-	-	-	-	-	OK 30DA ²	OK 84DA ²	OK 84DA ²
426669-19	1.00	0.020	0.333	0.167	8.4	-	-	-	-	-	-	OK 84DA ³	OK 30DA ³	OK 84DA ³
426669-12	1.00	0.023	0.500	0.200	8.7	-	-	-	-	-	-	OK 84DA	OK 84DA ⁴	OK 84DA
426669-11	1.00	0.025	0.500	0.333	13.2	-	-	-	-	-	-	OK 84DA	OK 84DA	OK 84DA ⁴
426669-22	1.00	0.046	1.000	0.500	10.9	-	-	-	-	-	-	OK 84DA ⁴	OK 84DA	OK 84DA
Recrystallized														
426669-21	2.00	0.031	0.143	0.067	2.2	68.4	64.1	4.0	OK 84DA	OK 84DA	OK 84DA	-	-	-
426669-18	1.00	0.040	0.333	0.200	5.0	-	-	-	-	-	-	OK 84DA ⁴	OK 84DA	OK 84DA
Unrecrystallized														
426669-15	2.00	-	-	-	-	74.3	64.9	10.0	Defective specimen	F 47DA	OK 84DA	-	-	-
437666-26B	2.00	-	-	-	-	72.7	64.0	9.0	OK 84DA	OK 84DA	OK 84DA	-	-	-
426669-14	1.00	-	-	-	-	-	-	-	-	-	-	OK 84DA ⁴	OK 84DA	OK 84DA

NOTES:

1. After 30-day and 84-day exposure, C-rings did not crack or show any visible evidence of lined-up pitting.
2. One specimen examined microscopically after 30 days and 2 specimens examined microscopically after 84 days. No evidence of stress-corrosion cracking noted after either 30- or 84-day exposure.
3. One specimen examined microscopically after 30 days and 2 specimens examined microscopically after 84 days. Slight evidence of stress-corrosion cracking after 30 days and no increase in the evidence of stress-corrosion cracking after 84 days.
4. Specimens examined microscopically after 84 days. No evidence of stress-corrosion cracking.
5. All specimens from T/2 location exposed stressed for 84 days by alternate immersion to 3.5% NaCl solution (Federal Test Method 823).
6. All forgings aged 24 hours at 250°F plus 8 hours at 350°F.

NOTES: 1. After 30-day and 84-day exposure, C-rings did not crack or show any visible evidence of lined-up pitting.

2. One specimen examined microscopically after 30 days and 2 specimens examined microscopically after 84 days. No evidence of stress-corrosion cracking noted after either 30- or 84-day exposure.

3. One specimen examined microscopically after 30 days and 2 specimens examined microscopically after 84 days. Slight evidence of stress-corrosion cracking after 30 days and no increase in the evidence of stress-corrosion cracking after 84 days.

4. Specimens examined microscopically after 84 days. No evidence of stress-corrosion cracking.

5. All specimens from T/2 location exposed stressed for 84 days by alternate immersion to 3.5% NaCl solution (Federal Test Method 823).

6. All forgings aged 24 hours at 250°F plus 8 hours at 350°F.

TABLE 16. GRAIN COUNTS, GRAIN DIMENSIONS, AND FABRICATING VARIABLES FOR 7475-T7X
HAND FORGINGS PRODUCED USING ITMT-TYPE PRACTICES

Warm Forging		Ingot Breakdown at 750°F, Reduction, N	Recry Temperature (°F)	Hot Forging at 750°F After Recry, Reduction, N	Grain Counts			Calculated Grain Dimensions				Forging Thickness (in.)	S.No.
Reduction, N	Temperature (°F)				Z	Y	X	Thickness I Z	Width Y	Length I X	Aspect Z X		
1.00- to 1.50-In.-Thick Recrystallized													
15.5	350	None	860	None	30	2	3	180	0.033	0.500	0.333	10.0	1.00 426669-23
15.5	400	None	860	None	24	2	2	96	0.042	0.500	0.500	11.9	1.00 426669-17
15.5	400	None	960	None	25	3	5	375	0.040	0.333	0.200	5.0	1.00 426669-18
13.0	400	2.8 + 3.1	960	None	53	16	26	22,048	0.019	0.062	0.038	2.0	1.00 437666-27A
13.0	400	2.8 + 3.1	960	None	16	3	6	288	0.062	0.333	0.167	2.7	1.00 426669-20
8.7	400	2.8 + 3.1	960	None	44	14	23	14,168	0.023	0.071	0.044	1.9	1.50 437666-27B
7.0	500	2.8 + 2.3	960	None	22	2	4	176	0.046	0.500	0.250	5.4	1.00 426669-8
4.0	500	2.8 + 4.0	960	None	24	3	8	576	0.042	0.333	0.125	3.0	1.00 426669-9
2.0	500	2.8 + 8.0	960	None	20	5	3	300	0.050	0.200	0.333	6.6	1.00 426669-10
1.75- to 2.25-In.-Thick Recrystallized													
7.4	400	2.8 + 3.1	960	None	41	10	14	5,740	0.024	0.100	0.071	3.0	1.75 437666-27C
6.5	400	2.8 + 3.1	960	None	32	7	15	3,360	0.031	0.143	0.067	2.2	2.00 426669-21
6.5	400	2.8 + 3.1	960	None	25	5	10	1,250	0.040	0.200	0.100	2.5	2.00 437666-27D
5.8	400	2.8 + 3.1	960	None	29	10	17	4,930	0.034	0.100	0.059	1.7	2.25 437666-27E
1.8 + 4.0	500	2.8 + 2.3	960	None	17	2	3	102	0.059	0.500	0.333	5.6	2.00 426669-16
4.0	500	2.8 + 2.0	960	None	6	1	1	6	0.167	1.000	1.000	5.9	2.00 426669-3
2.0	500	2.8 + 4.0	960	None	19	2	7	266	0.053	0.500	0.143	2.7	2.00 426669-2
1.00-In.-Thick Recrystallized Plus Hot-Forged													
2.6 + 2.6 + 7.7	400	2.8 + 3.1	960	1.7	57	2	12	1,368	0.018	0.500	0.083	4.6	1.00 437666-28A
9.1	400	None	860	1.7	22	1	2	44	0.046	1.000	0.500	10.9	1.00 426669-22
9.1	500	None	860	1.7	19	1	1	19	0.053	1.000	1.000	18.9	1.00 426669-13
9.1	550	None	860	1.7	Unrecrystallized								1.00 437666-26A
7.7	400	2.8 + 3.1	960	1.7	50	3	6	900	0.020	0.333	0.167	8.4	1.00 426669-19
4.1	500	2.8 + 2.3	960	1.7	40	2	3	240	0.025	0.500	0.33	13.2	1.00 426669-11
2.1	500	2.8 + 4.6	960	1.7	43	2	5	430	0.023	0.500	0.200	8.7	1.00 426669-12
2.00-In.-Thick Recrystallized Plus Hot-Forged													
2.6 + 2.6 + 3.8	400	2.8 + 3.1	960	1.8	33	4	10	1,320	0.030	0.250	0.100	3.3	2.00 437666-28B
2.0 + 2.3 + 2.7	500	2.8 + 2.0	960	1.5	24	2	4	192	0.042	0.500	0.250	6.0	2.00 426669-6
4.4	500	None	860	1.8	Unrecrystallized								2.00 426669-7
4.4	550	None	860	1.8	Unrecrystallized								2.00 437666-26B
2.0 + 2.3	500	2.8 + 2.3	960	1.8	28	1	1	28	0.036	1.000	1.000	27.7	2.00 426669-5
2.0	500	2.8 + 2.3	960	1.8	36	1	1	36	0.038	1.000	1.000	35.7	2.00 426669-4

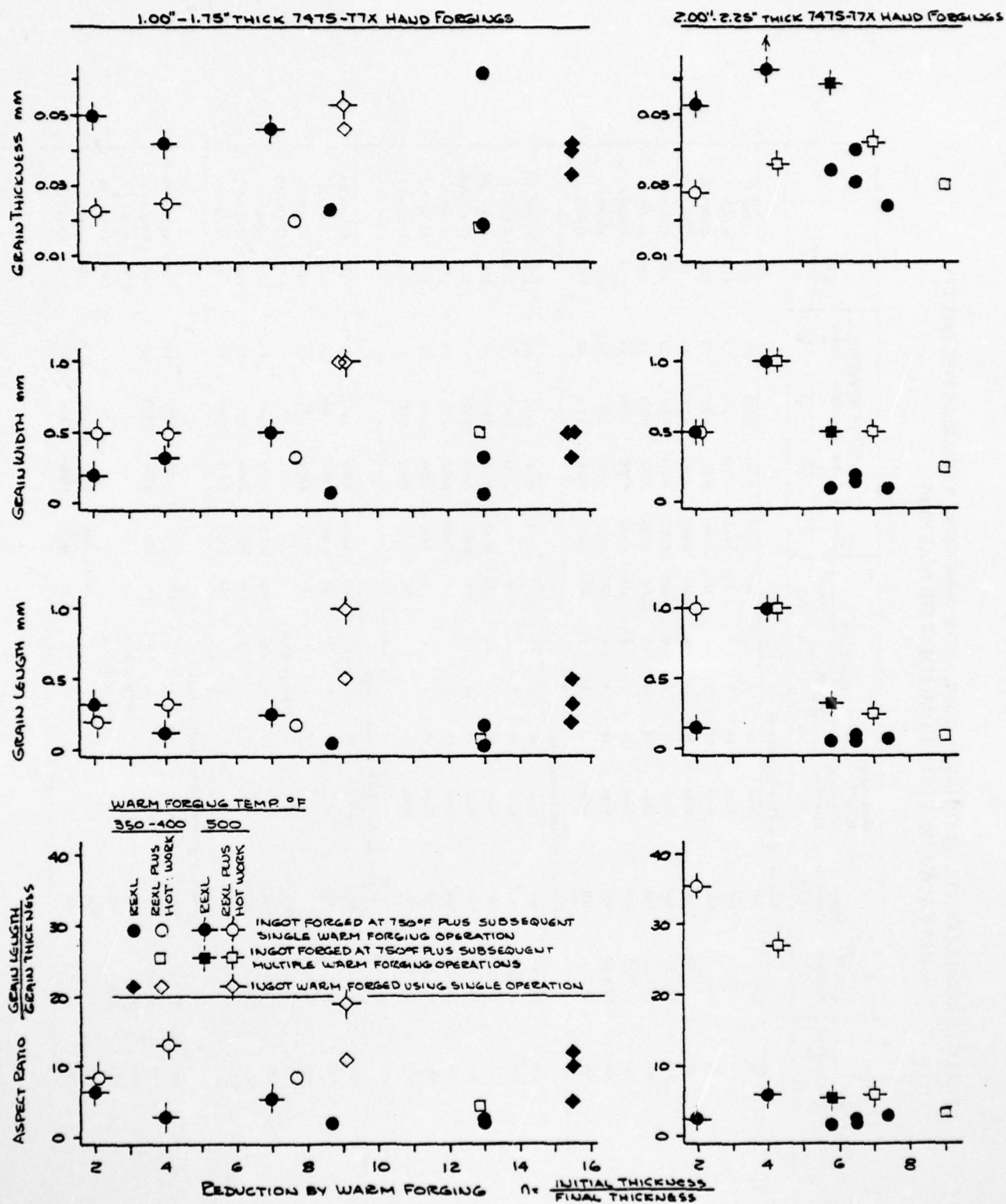


Figure 38. Relationship Between Grain Dimensions and Amount of Warm Forging for 1- to 2.25-Inch-Thick 7475-T7X ITMT Hand Forgings.

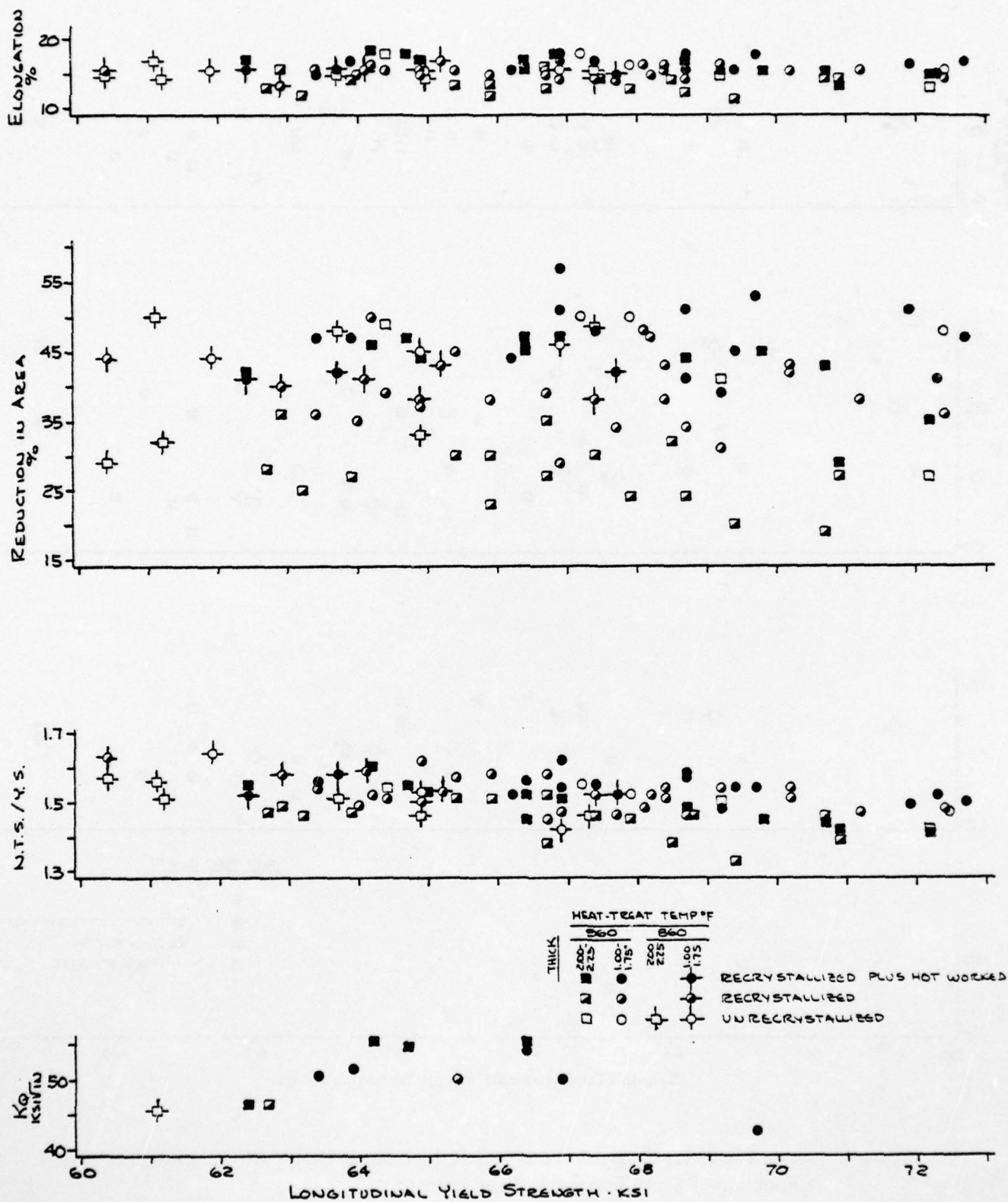


Figure 39. Longitudinal Properties of 1- to 2.25-Inch-Thick 7475-T7X Hand Forgings as a Function of Yield Strength.

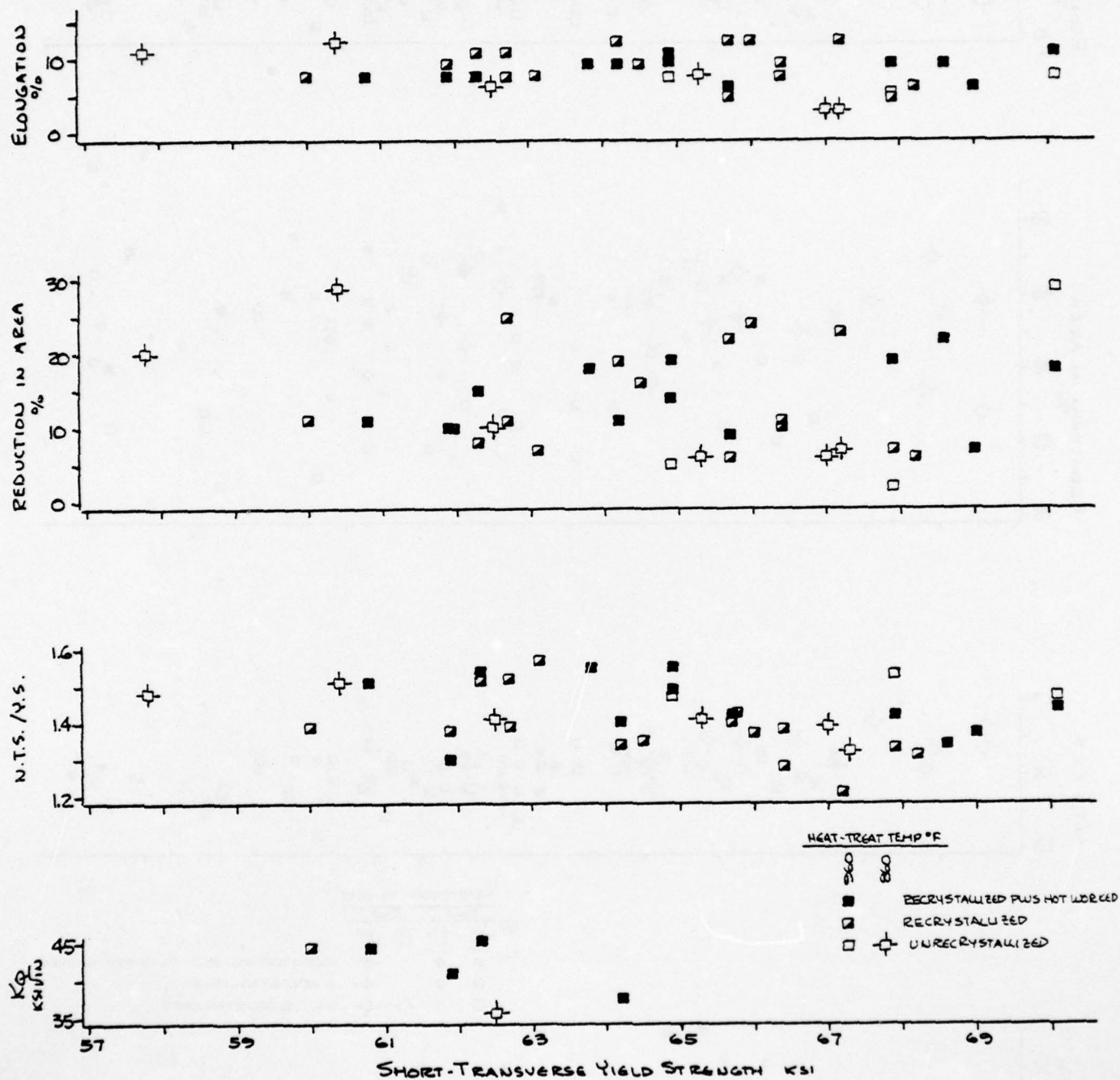


Figure 40. Short-Transverse Properties of 2- to 2.25-Inch-Thick 7475-T7X Hand Forgings as a Function of Short-Transverse Yield Strength.

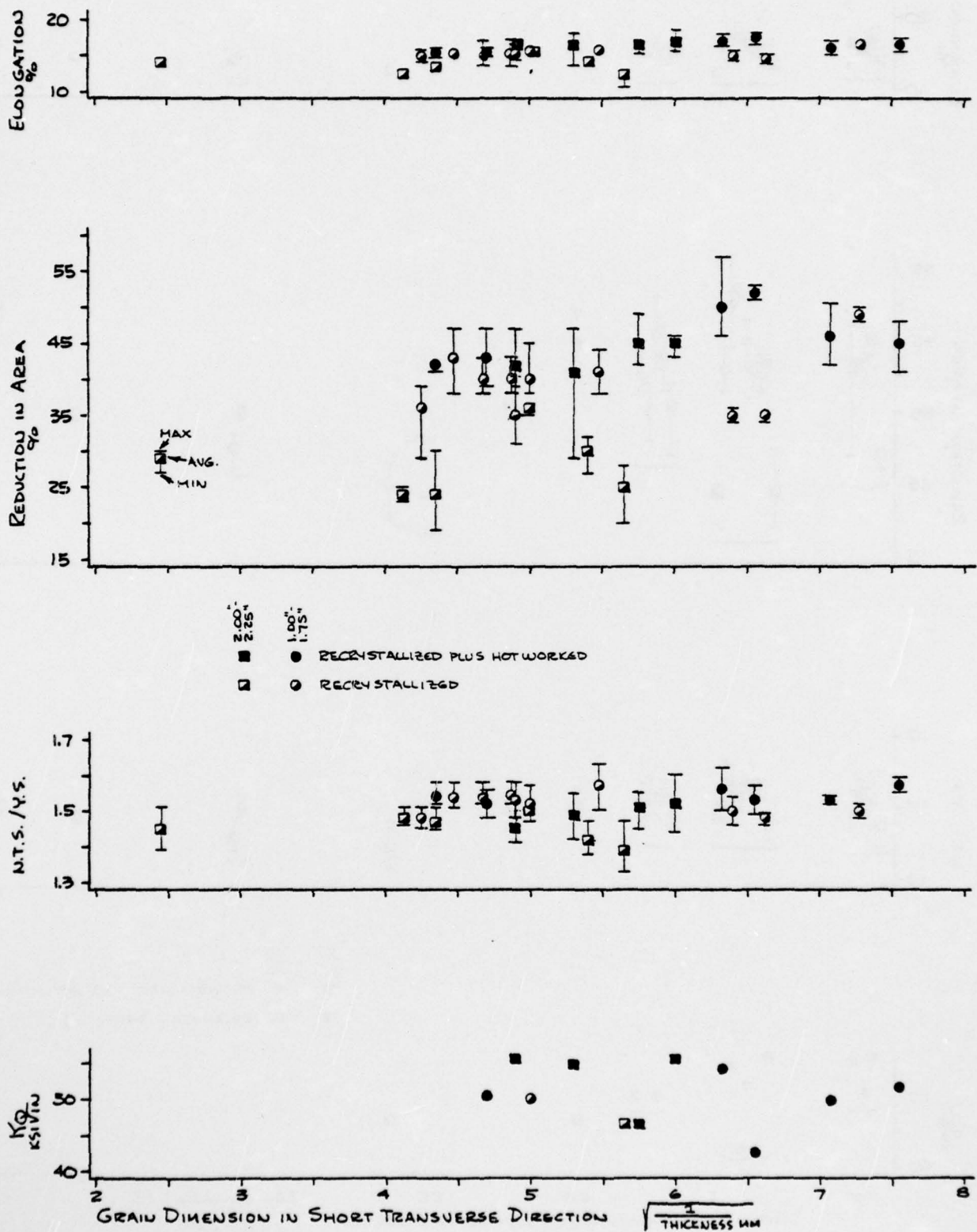


Figure 41. Longitudinal Properties of 1- to 2.25-Inch-Thick 7475-T7X Hand Forgings as a Function of the Grain Dimension in the Short-Transverse Direction.



Figure 42. Longitudinal Properties of 1- to 2.25-Inch-Thick 7475-T7X Hand Forgings as a Function of the Grain Dimension in the Long-Transverse Direction.

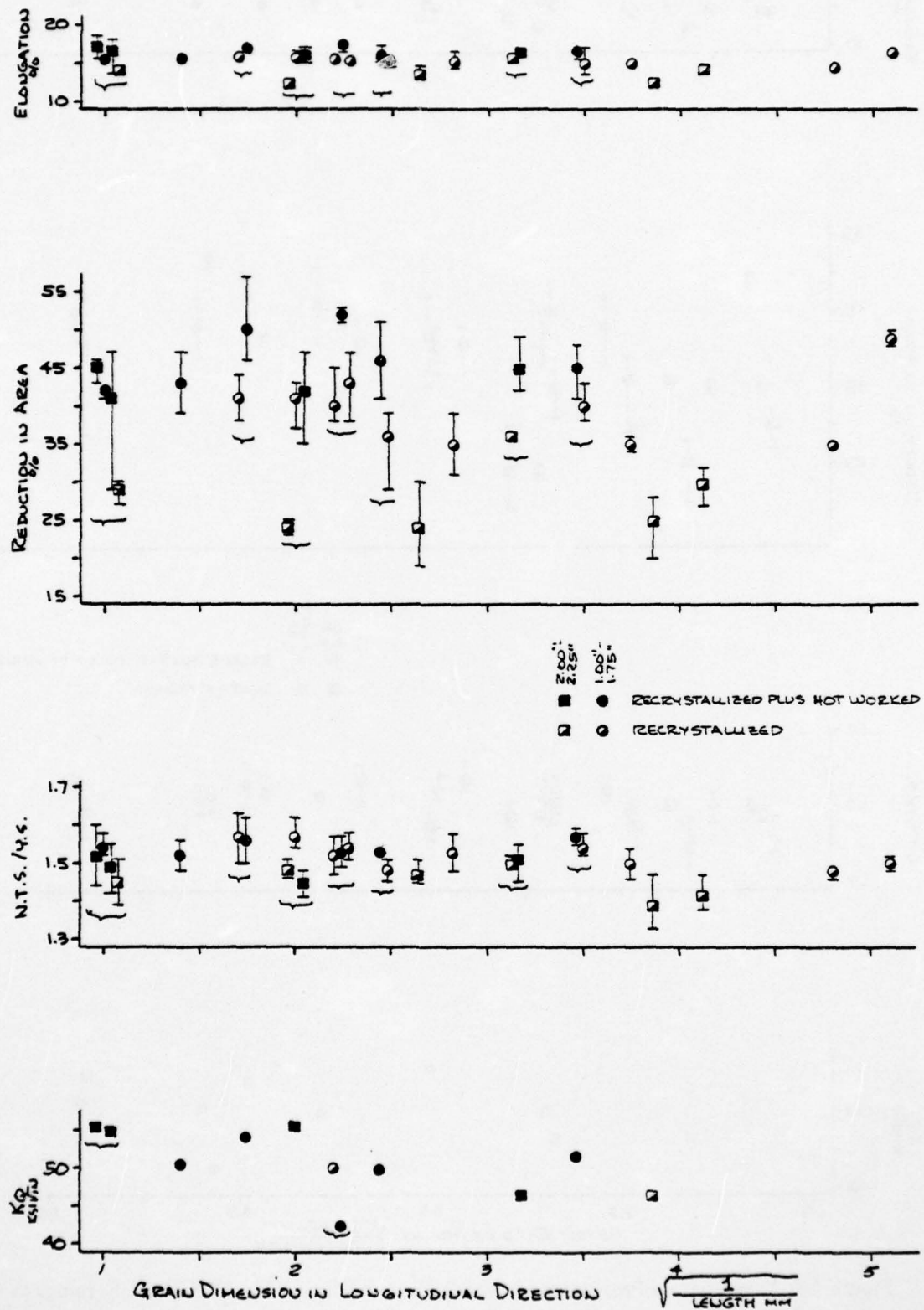


Figure 43. Longitudinal Properties of 1- to 2.25-Inch-Thick 7475-T7X Hand Forgings as a Function of the Grain Dimension in the Longitudinal Direction.

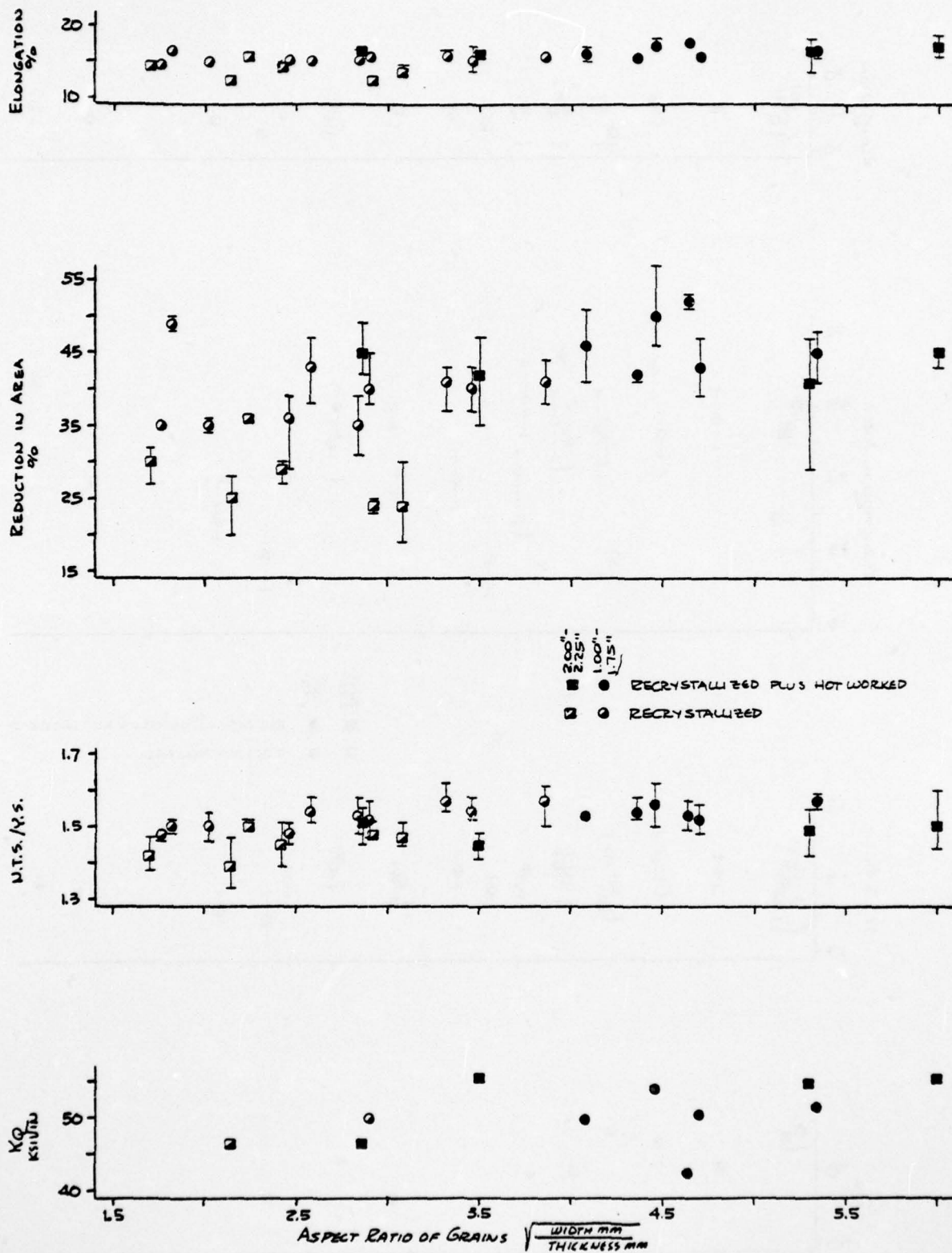


Figure 44. Longitudinal Properties of 1- to 2.25-Inch-Thick 7475-T7X Hand Forgings as a Function of the Width and Thickness of the Grains.

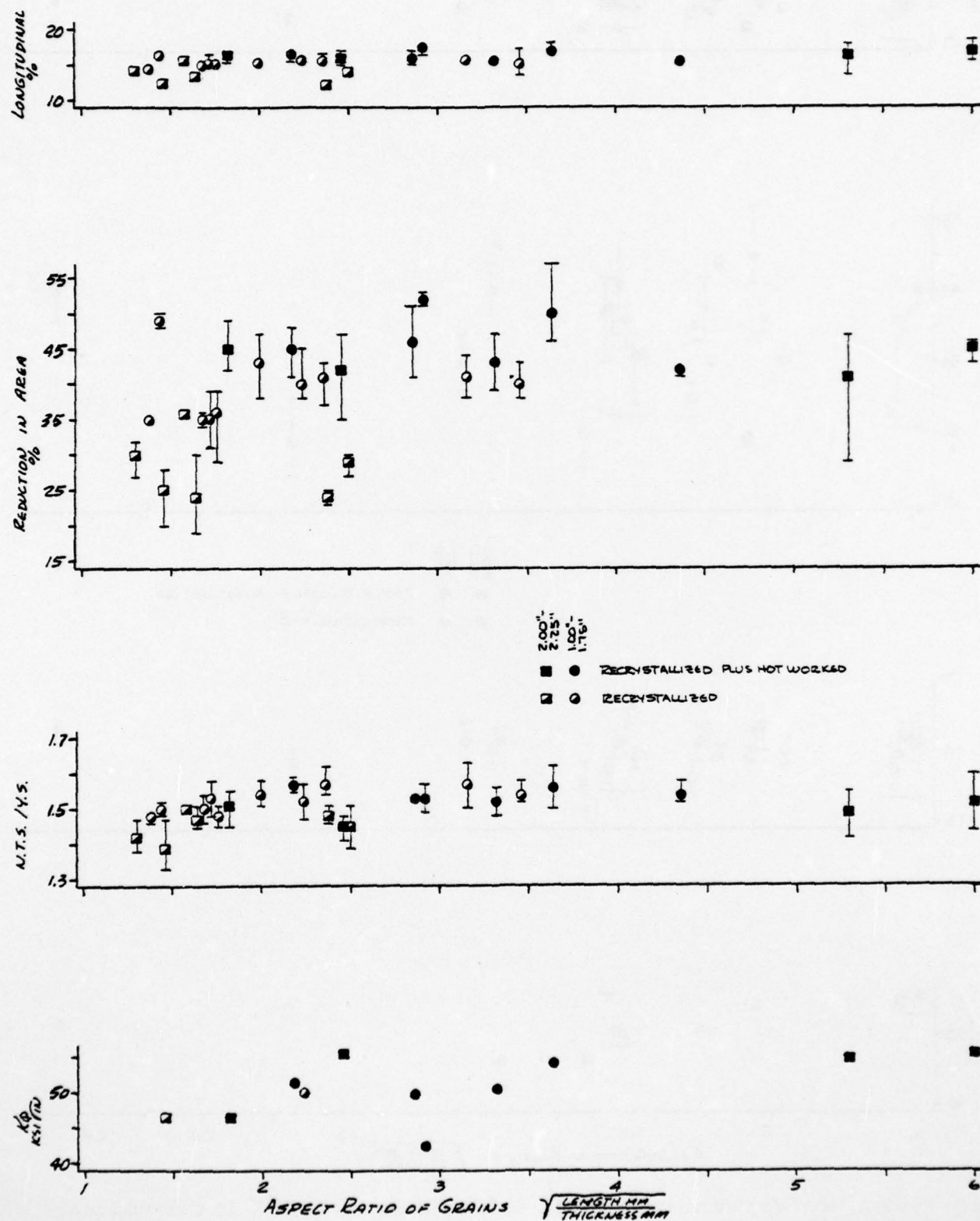


Figure 45. Longitudinal Properties of 1- to 2.25-Inch-Thick 7475-T7X Hand Forgings as a Function of the Length and the Thickness of the Grains.

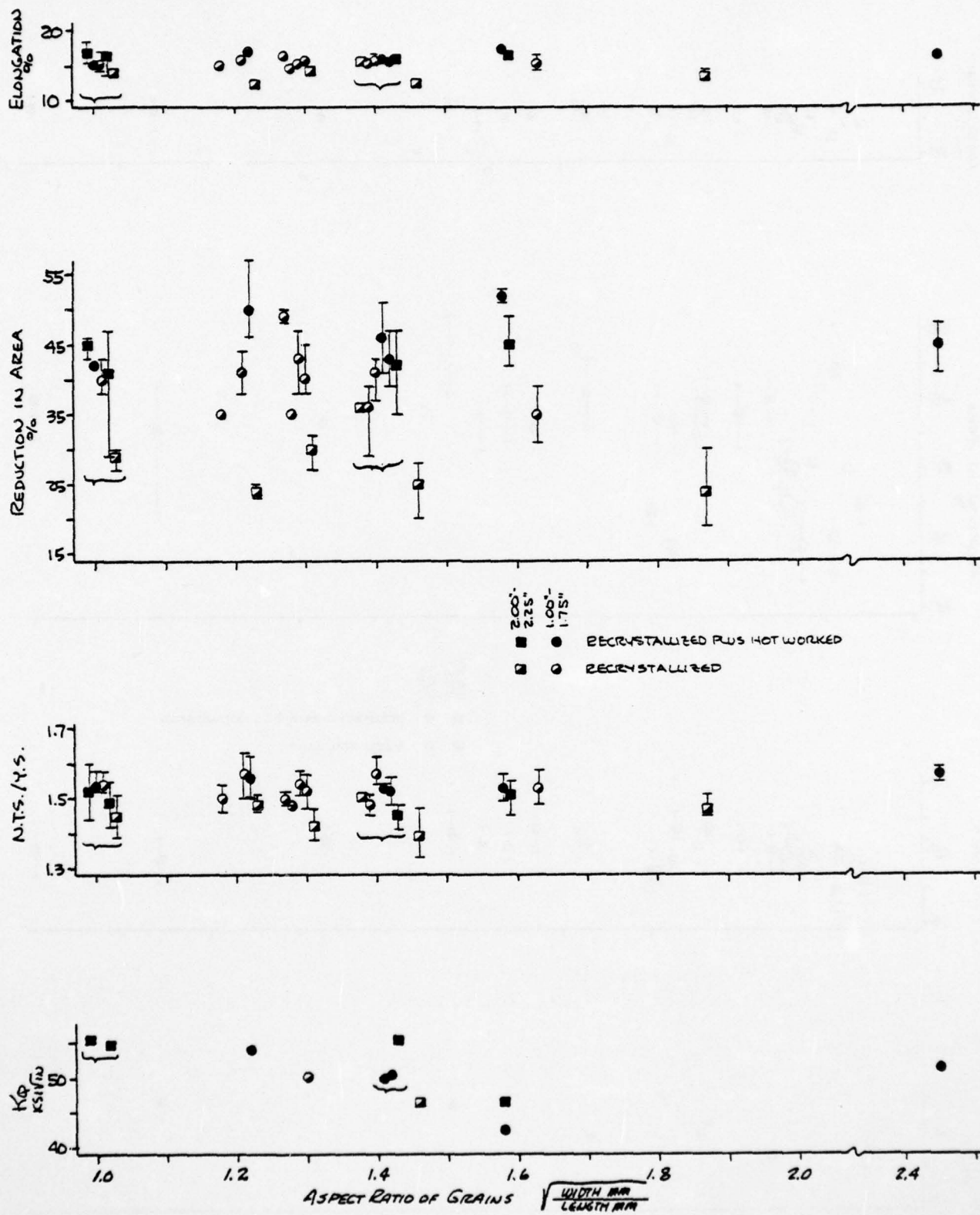


Figure 46. Longitudinal Properties of 1- to 2.25-Inch-Thick 7475-T7X Hand Forgings as a Function of the Width and Length of the Grains.

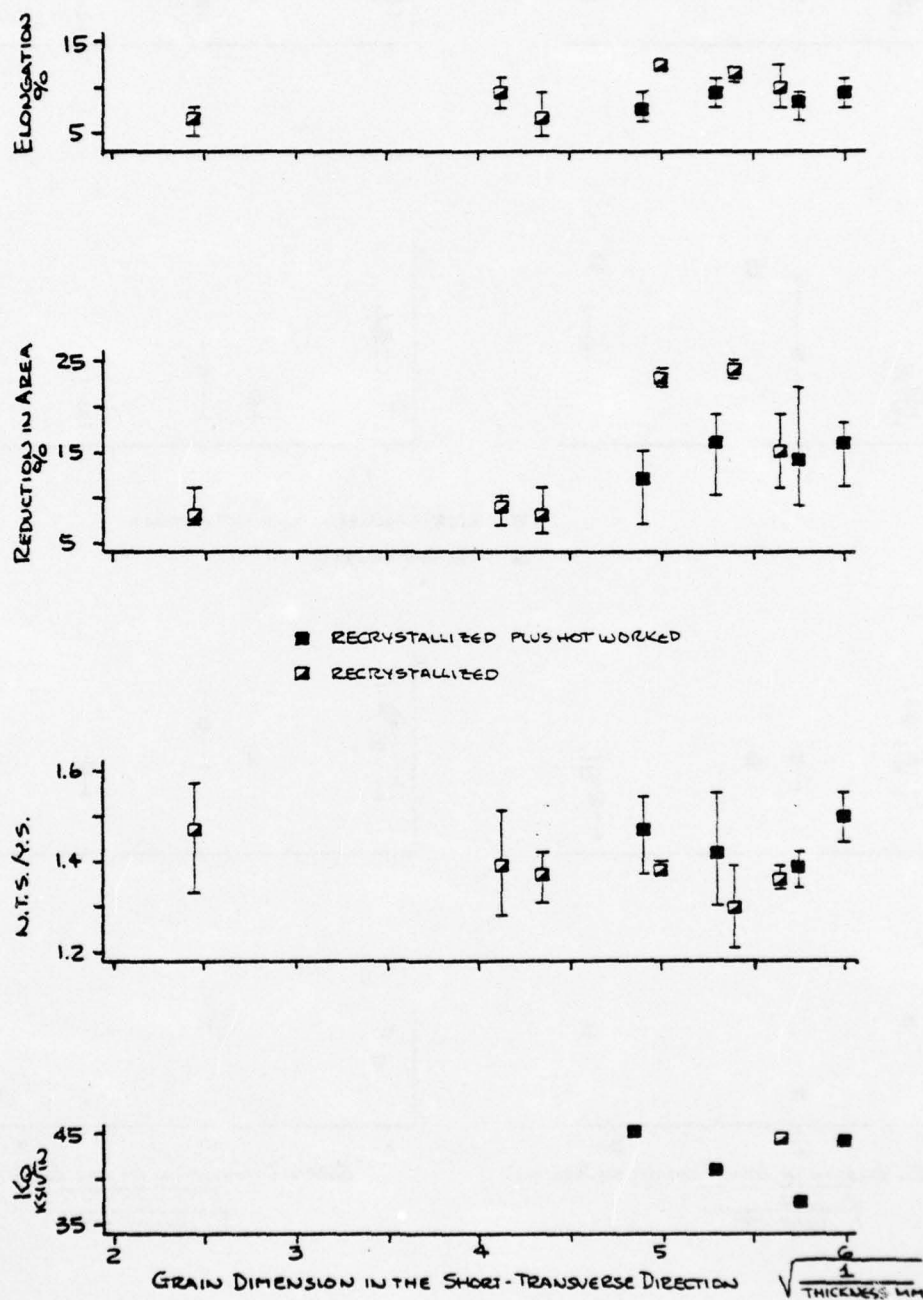


Figure 47. Short-Transverse Properties of 2- to 2.25-Inch-Thick 7475-T7X Hand Forgings as a Function of the Grain Dimension in the Longitudinal Direction.

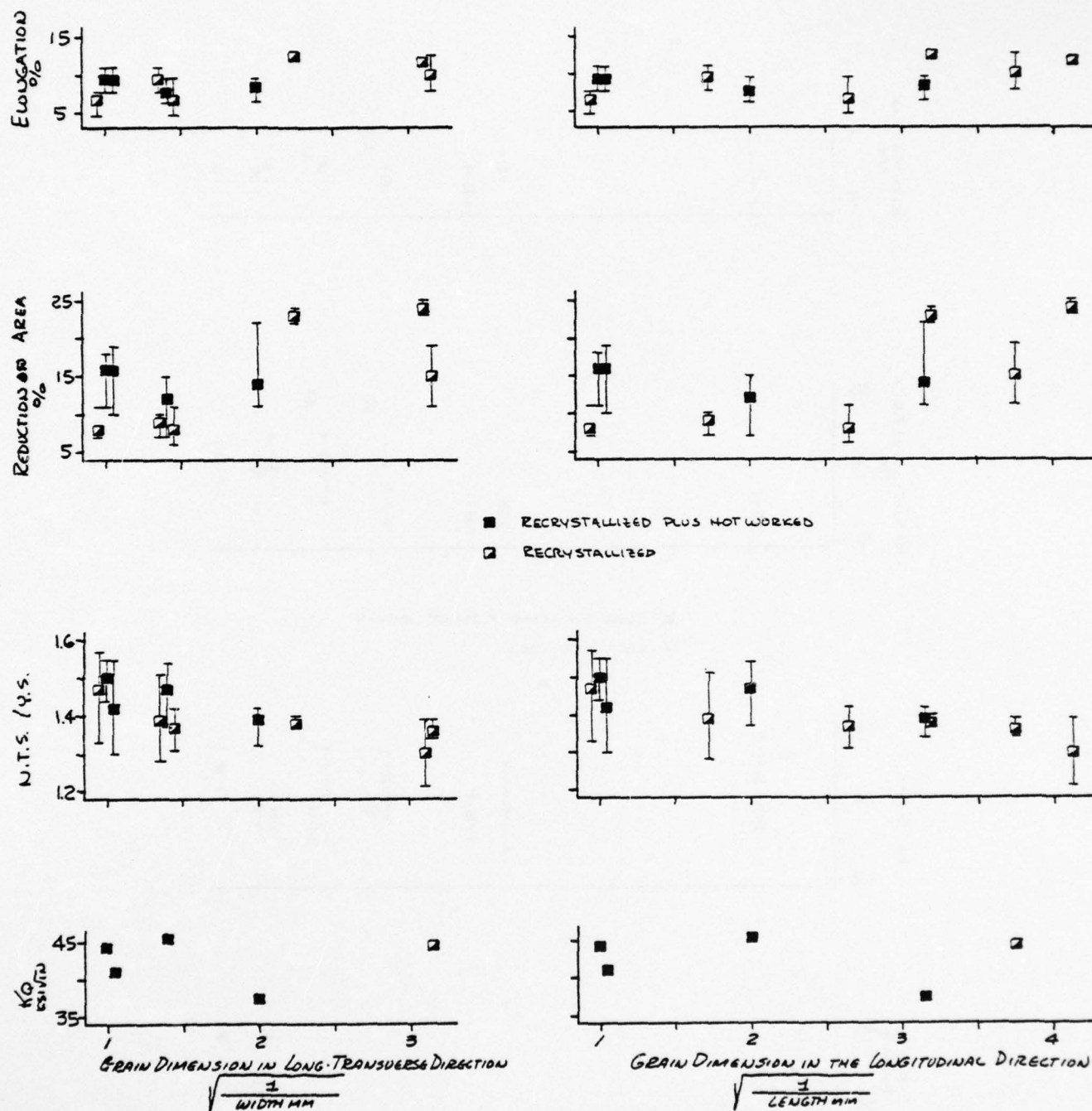


Figure 48. Short-Transverse Properties of 2- to 2.25-Inch-Thick 7475-T7X Hand Forgings as a Function of the Grain Dimensions in the Longitudinal and Long-Transverse Directions.

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IMPROVEMENT OF HELICOPTER FORGINGS BY CONTROLLED SOLIDIFICATION--ETC(U)
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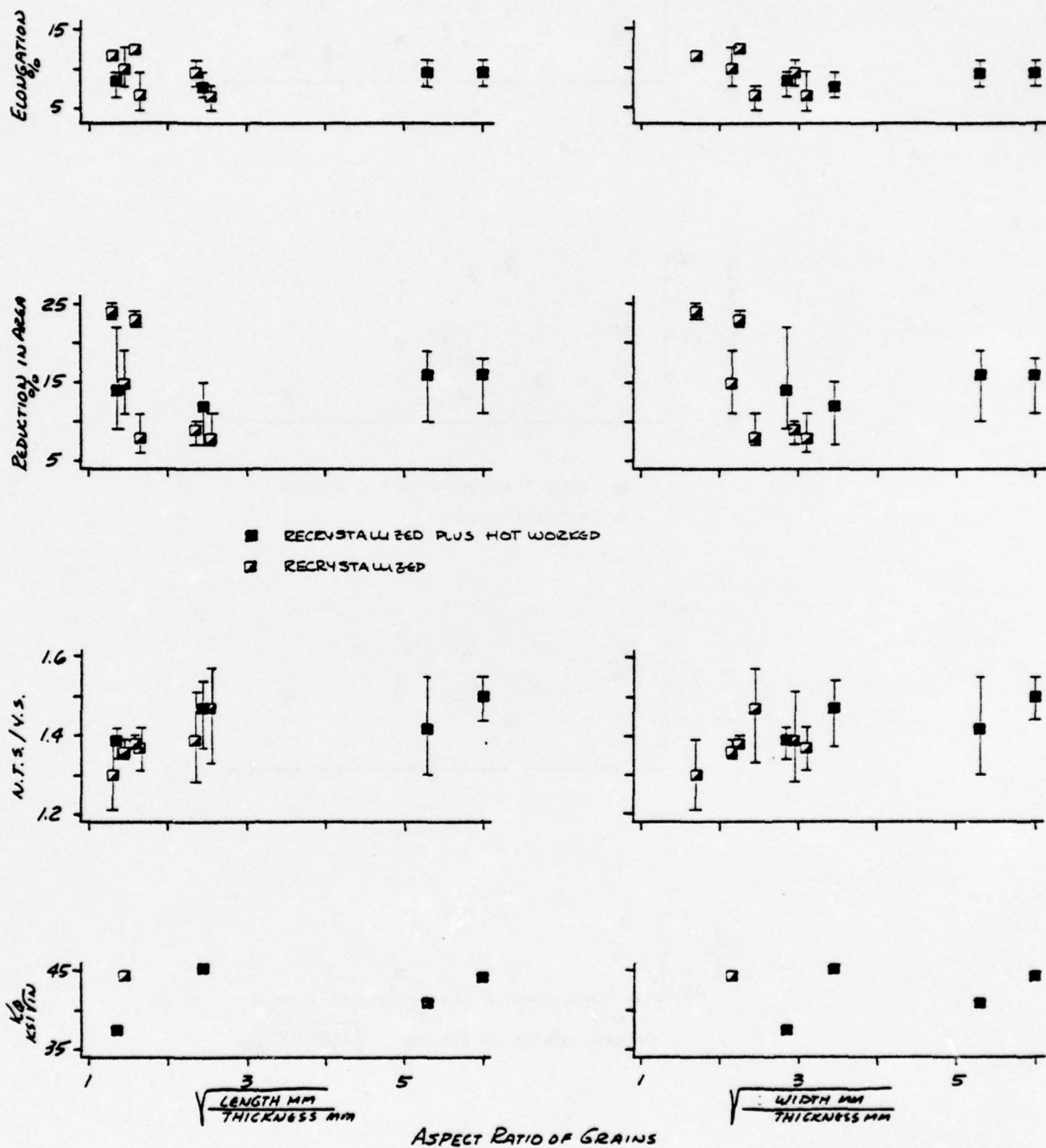


Figure 49. Short-Transverse Properties of 2- to 2.25-Inch-Thick 7475-T7X Hand Forgings as a Function of the Length, Width, and Thickness of the Grains.

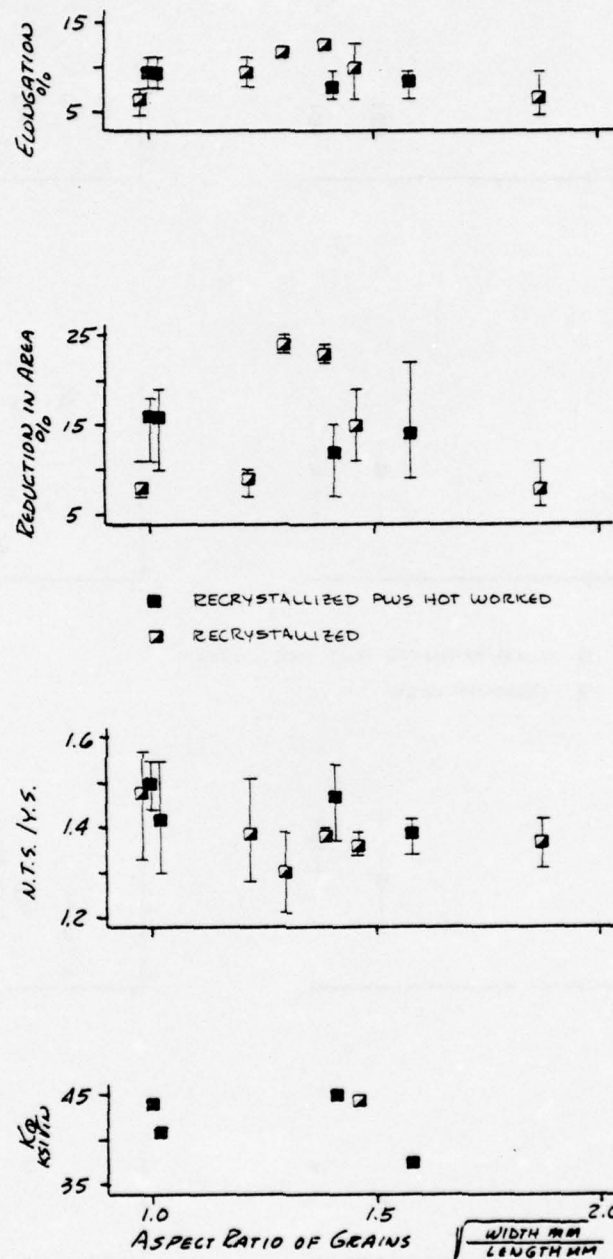


Figure 50. Short-Transverse Properties of 2- to 2.25-Inch-Thick 7475-T7X Hand Forgings as a Function of the Length and Width of the Grains.

TASK II - PRODUCTION OF FORGINGS

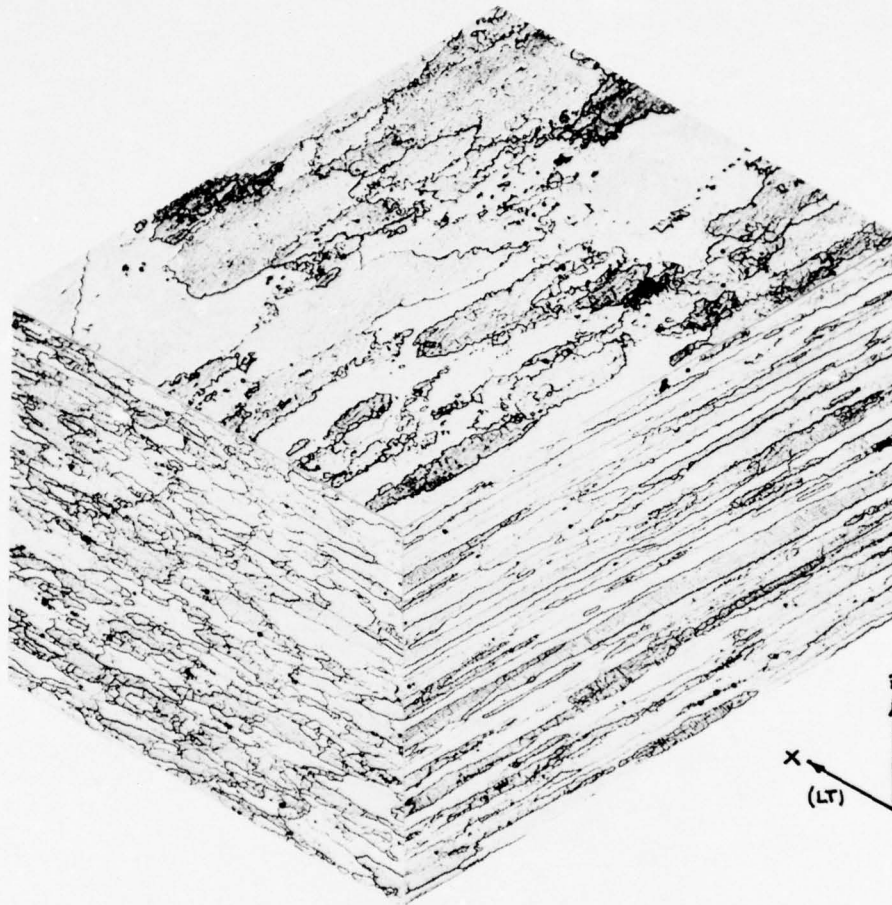
The goal of Task II was the fabrication of 6.7-, 2.0-, and 1.0-inch-thick 7075 and 7475 hand forgings in the F temper at the Cleveland Plant of Alcoa and the heat treatment of the forgings at Alcoa Laboratories to supply forgings in the T73 temper for testing by Boeing Vertol and Alcoa Laboratories. The three thicknesses of 7075 forgings were produced as a stepped forging from commercial ingot using a commercial fabricating practice. The three thicknesses of 7475 forgings were produced by two experimental fabricating practices from 17-inch-diameter ingot cast at Alcoa Laboratories. The practices used were of the Intermediate-Thermal-Mechanical-Treatment (ITMT) type and were selected to produce forgings having a recrystallized-plus-hot-worked structure. By mutual agreement, Boeing Vertol, Alcoa, and Frankford Arsenal selected ITMT practices 426669-19 and 437666-28A in Task I to be used as the two ITMT practices in Task II. This selection was based on microstructure evaluation, tensile properties, fracture-toughness characterization, and stress-corrosion-cracking performance of the 31 hand forgings.

Based on commercial forging restraints and the ingot size available, the two ITMT practices in Task I were then equated to produce 6.7-, 2.0-, and 1.0-inch-thick 7475 hand forgings having a recrystallized-plus-hot-worked structure. The practices based on the practice used to produce forging S-426669-19 are described pictorially in Figures 51, 52, and 53 and are identified subsequently in this report as 7475-TMT1. The practices based on the practice used to produce forging S-437666-28A are described pictorially in Figures 54, 55, and 56 and are identified subsequently as 7475-TMT2.

The reductions used during the forging sequences are compared in Table 17.

The solution-heat treatment, quenching, and artificial aging of the forgings at Alcoa Laboratories are described in Figure 57 for the 7075-T73 forgings and in Figure 58 for the 7475-T73 forgings. The 6.7-inch-thick forgings were fabricated so that short-transverse fatigue tests could be made by Boeing Vertol. However, to minimize the effect of quench rate in comparing the properties obtained on the 6.7-inch-thick forgings with the properties obtained on the 2- and 1-inch-thick forgings, 2-inch-thick sections were sawed from the 6.7-inch-thick forgings and thermally treated as indicated. The time of the second-step aging practice used for the 7475 forgings was longer than that used for 7075-T73 because the results of the accelerated stress-corrosion tests carried out in Task I indicated that the standard 7075-T73 second-step aging practice might not produce a satisfactory resistance to stress-corrosion cracking in the short-transverse direction in 7475-T73 hand forgings.

The grain dimensions of the 7475-T73 hand forgings having a recrystallized-plus-hot-worked structure are given in Table 17. Three-dimensional photomicrographs of the structures of samples of the hand forgings are presented in Figures 51 through 56 for the 7475-T73 hand forgings having a recrystallized-plus-hot-worked structure, in Figures 59 through 61 for the 7075-T73 hand forgings.



Mag 100X

Keller's Etch

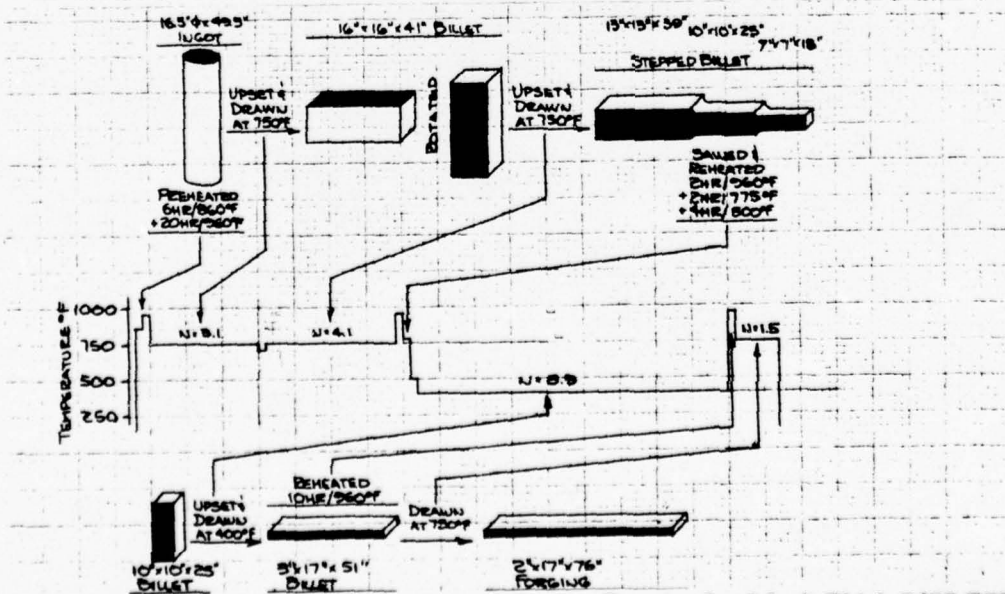
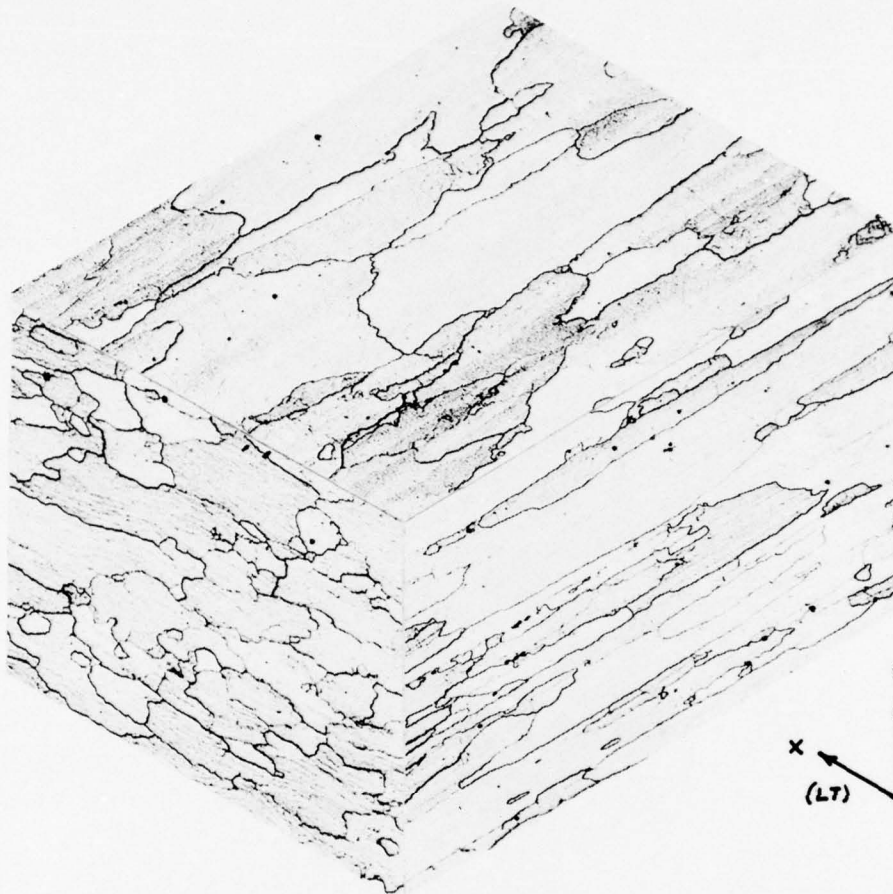


Figure 52. Microstructure Properties and Forging Practice for 2-Inch-Thick 7475-T73 Task II Forging, S-438169.



Mag 100X

Keller's Etch

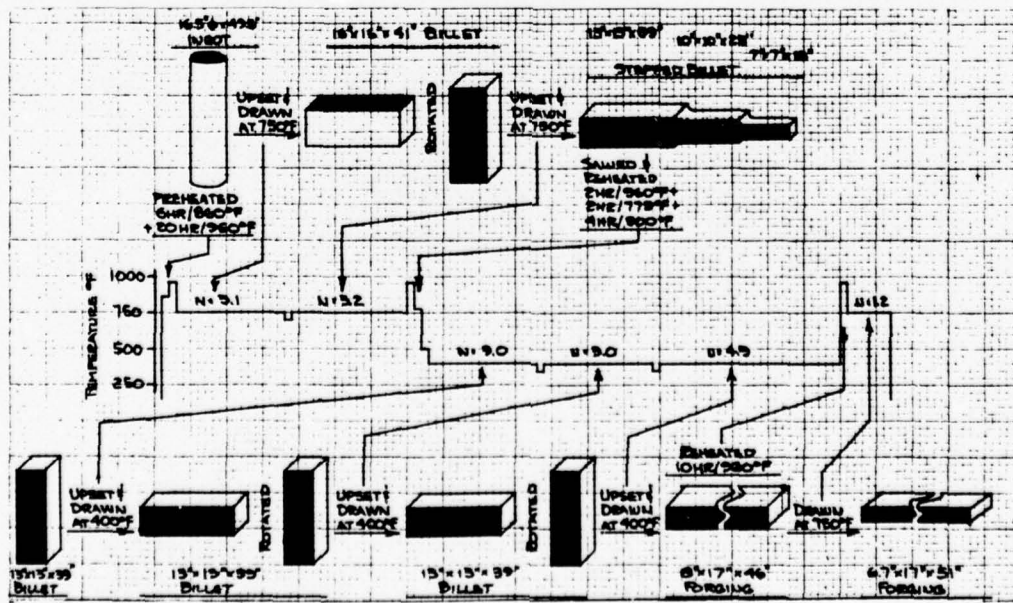


Figure 54. Microstructure Properties and Forging Practice for 6.7-Inch-Thick 7475-T73 Task II Forging, S-438173.

TABLE 17. FABRICATING DETAILS FOR 7475 HAND FORGINGS PRODUCED BY ITMT-TYPE PROCEDURES

Finished Hand Forging				Initial Forging of 16.5 ϕ x 49-In. Ingot at 750°F ¹		Warm Forging of Billet at 400°F ²		Forging of Recrystallized Billet at 750°F ³		Finished Size of Forging (in.)
S.No.	Grain Dimensions			Type of Forging Operation	Reduction, N	Initial Size (in.)	Type of Forging Operation	Reduction, N	Initial Size (in.)	
	Thickness (mm)	Width (mm)	Length (mm)							
6.7-In.-Thick Hand Forgings										
438170	0.042	0.083	0.125	Upset & draw	3.1	13x13x39	Upset & draw	4.9	Draw	6.7x17x51
438173	0.036	0.083	0.200	Upset & draw	3.1	13x13x39	Upset & draw	3.0		
				Upset & draw	3.2		Upset & draw	3.0		
				Upset & draw			Upset & draw	4.9	Draw	6.7x17x51
2.0-Inch-Thick Hand Forgings										
438169	0.010	0.029	0.067	Upset & draw	3.1	10x10x25	Upset & draw	8.3	Draw	2.0x17x76
438172	0.015	0.071	0.250	Upset & draw	3.1	10x10x25	Upset & draw	2.5		
				Upset & draw	4.1		Upset & draw	2.5		
				Upset & draw			Upset & draw	8.3	Draw	2.0x17x76
1.0-Inch-Thick Hand Forging										
438168	0.013	0.062	0.091	Upset & draw	3.1	7x7x18	Upset & draw	12.0	Draw	1.0x17x51
438171	0.020	0.091	0.143	Upset & draw	3.1	7x7x18	Upset & draw	2.6		
				Upset & draw	5.9		Upset & draw	2.6		
				Upset & draw			Upset & draw	12.0	Draw	1.0x17x51

NOTES:

1. Ingot preheated 6 hours at 860°F; plus 20 hours at 960°F prior to forging at 750°F.
2. Billet reheated 2 hours at 960°F; furnace cooled to 775°F, soaked 2 hours at 775°F, furnace cooled to 500°F, and soaked 4 hours at 500°F prior to warm-forging at 400°F.
3. Forging reheated 10 hours at 960°F after warm-forging at 400°F and prior to forging at 750°F.
4. Reduction, N = $\frac{\text{original thickness in direction of greatest reduction}}{\text{final thickness in direction of greatest reduction}}$
5. Composition of ingot: Cu, 1.55; Mg, 2.37; Zn, 5.73; Fe, 0.06; Si, 0.04; Cr, 0.20; Ti, 0.02; Be, 0.002.

- NOTES:
1. Ingot preheated 6 hours at 860°F; plus 20 hours at 960°F prior to forging at 750°F.
 2. Billet reheated 2 hours at 960°F, furnace cooled to 775°F, soaked 2 hours at 775°F, furnace cooled to 500°F, and soaked 4 hours at 500°F prior to warm-forging at 400°F.
 3. Forging reheated 10 hours at 960°F after warm-forging at 400°F and prior to forging at 750°F.
 4. Reduction, N = $\frac{\text{original thickness in direction of greatest reduction}}{\text{final thickness in direction of greatest reduction}}$
 5. Composition of ingot: Cu, 1.55; Mg, 2.37; Zn, 5.73; Fe, 0.06; Si, 0.04; Cr, 0.20; Ti, 0.02; Be, 0.002.

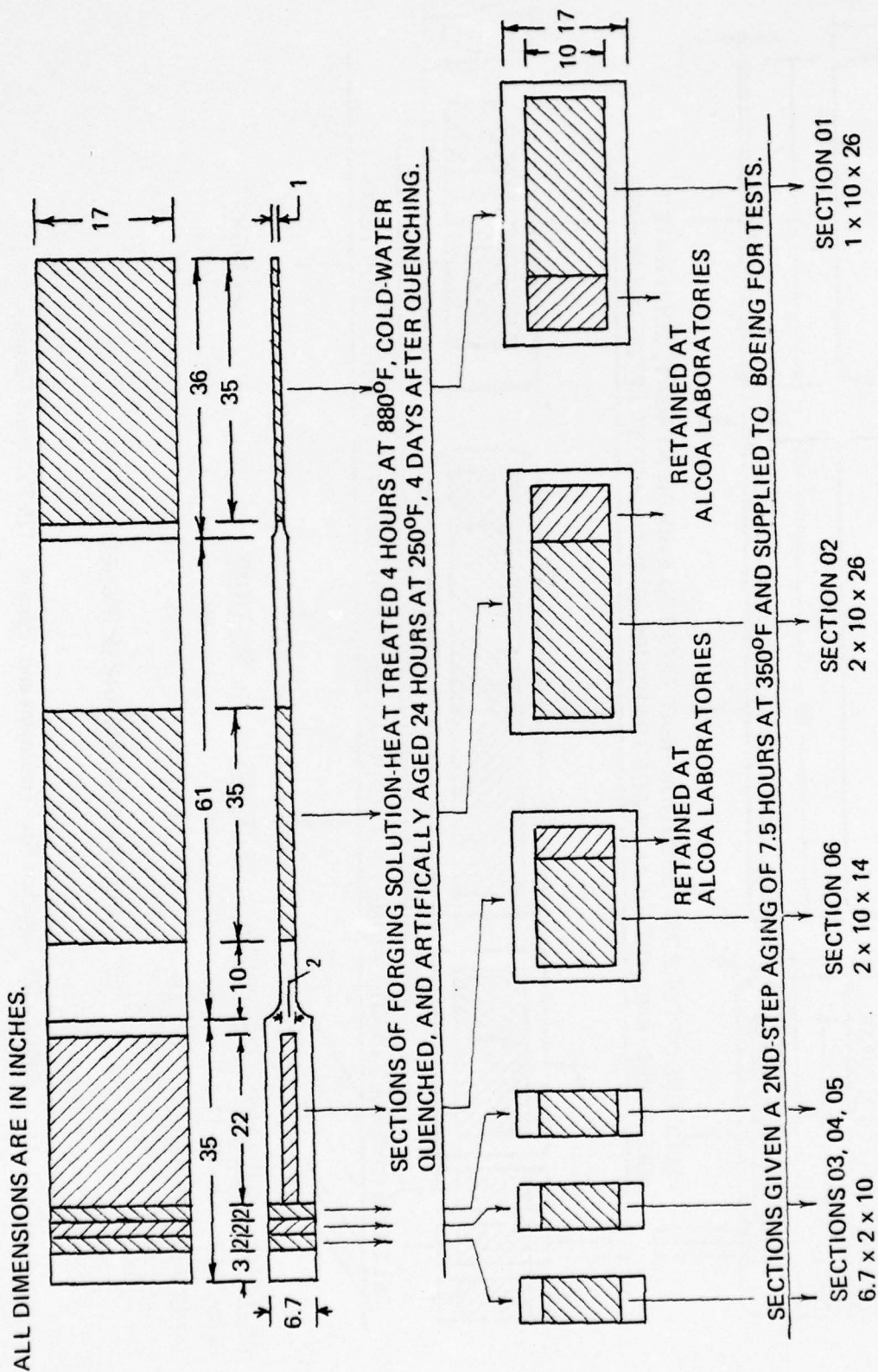
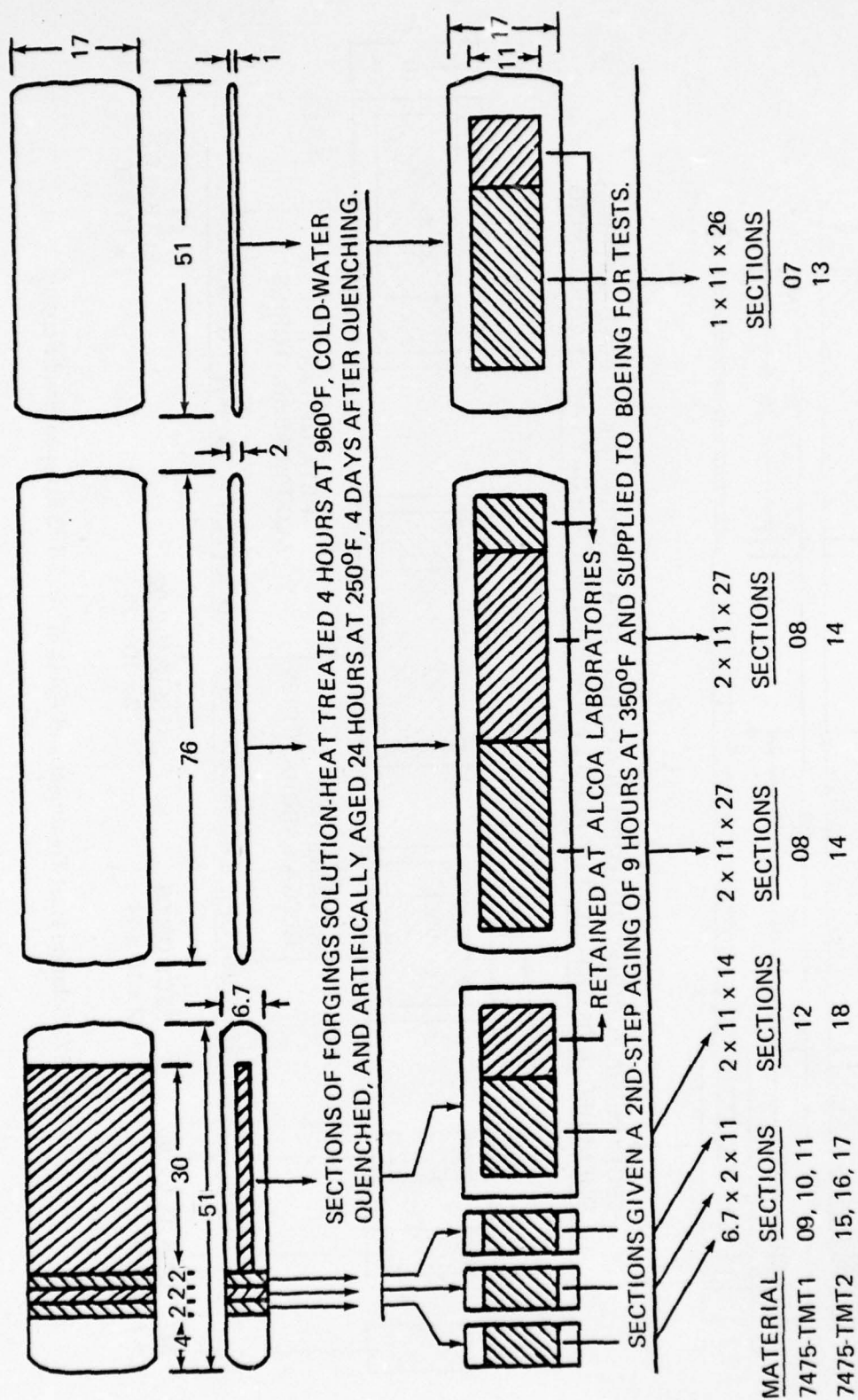
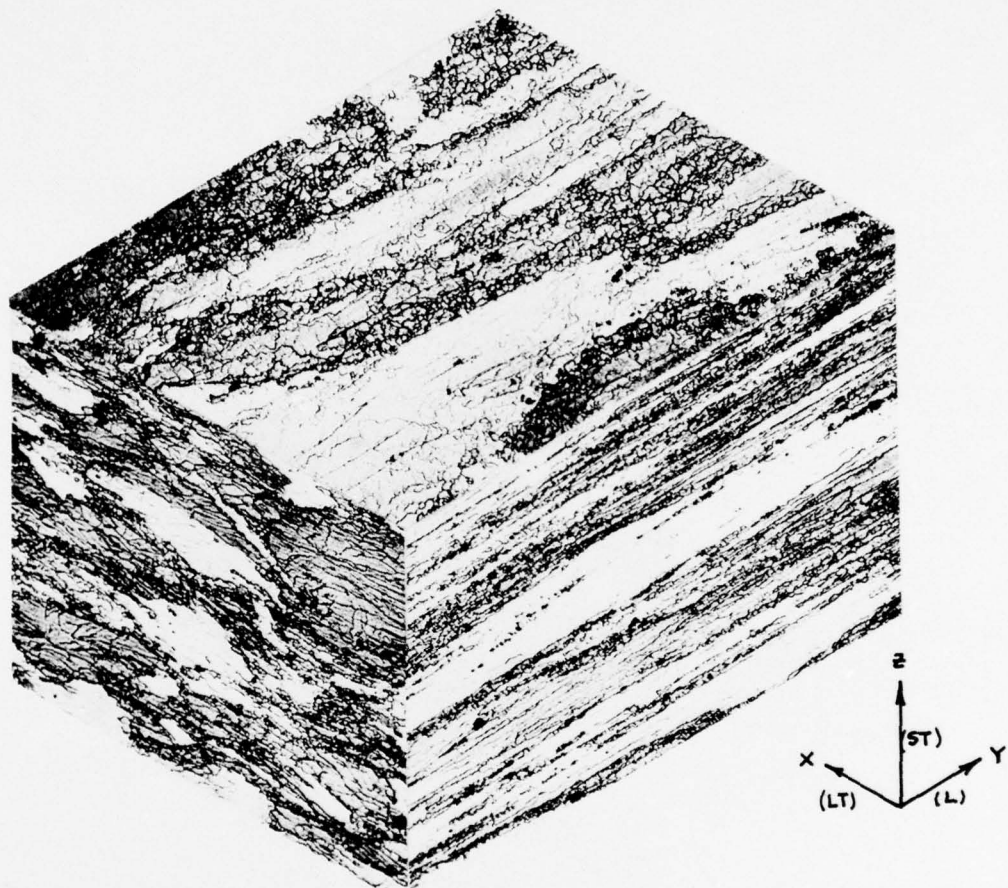


Figure 57. Solution Heat Treatment and Aging of 7075-T73 Stepped Hand Forging.



ALL DIMENSIONS ARE IN INCHES

Figure 58. Solution Heat Treatment and Aging of 7475-T73 Hand Forgings.

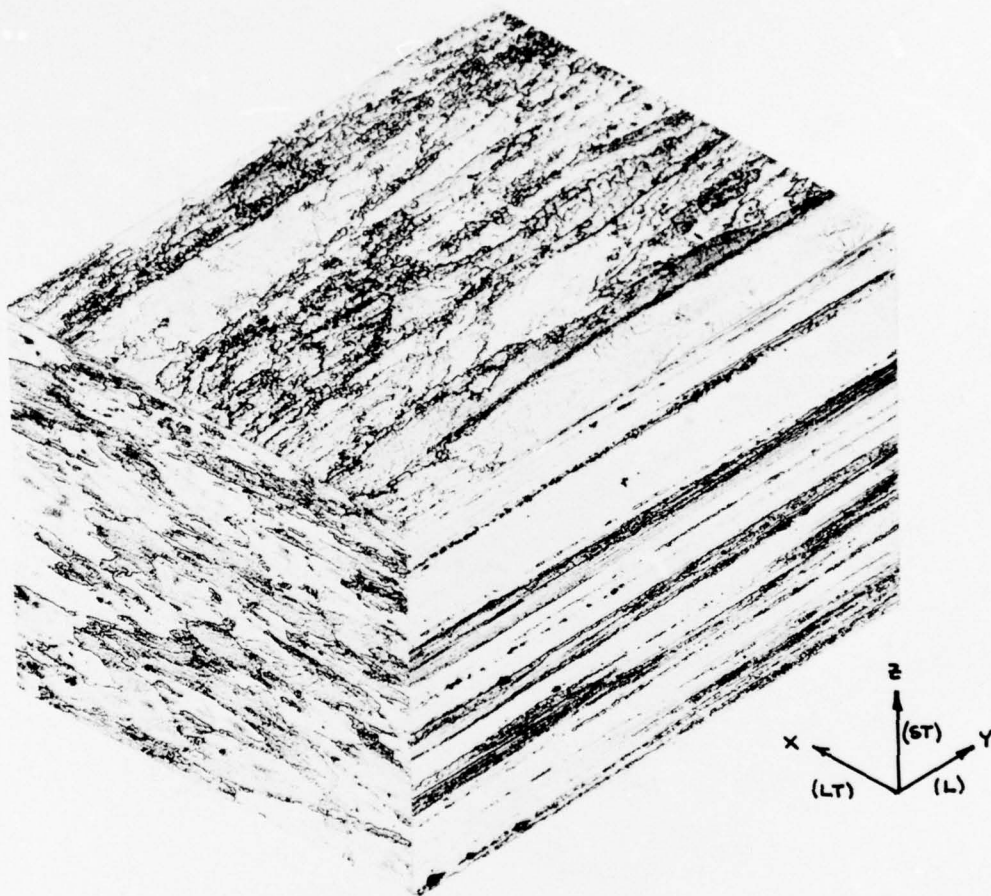


Mag 100X

Keller's Etch

6.70" Thick 7075-T73 Hand Forging

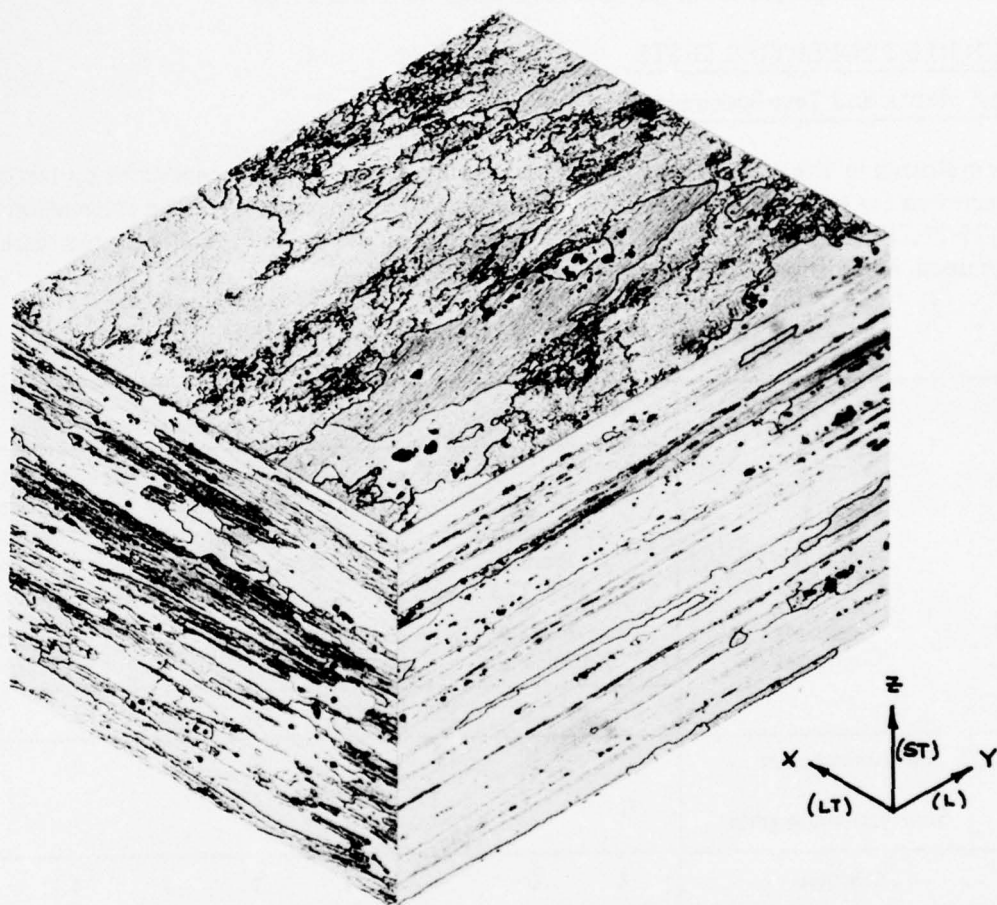
Figure 59. Microstructure Properties for 6.7-Inch-Thick 7075-T73 Task II Forging, S-437701-3.



Mag 100X
2.00" Thick 7075-T73 Hand Forging

Keller's Etch

Figure 60. Microstructure Properties for 2-Inch-Thick 7075-T73 Task II Forging, S-437701-2.



Mag 100X
1.00" Thick 7075-T73 Hand Forging

Keller's Etch

Figure 61. Microstructure Properties for 1-Inch-Thick 7075-T73 Task II Forging, S-437701-1.

TASK III – MECHANICAL-PROPERTIES TESTS

The mechanical properties of all Task II forgings were measured.

TENSILE-PROPERTIES TESTS

Test Matrix and Test-Specimen Configuration

As indicated in Table 18, tensile properties of Task II forgings were measured by testing 10 specimens for each of the selected TMT forgings and 10 specimens for the conventional 7075-T73 forgings. The short-transverse properties of the 6.7-inch-thick forgings were determined, in addition to the longitudinal properties.

TABLE 18. TENSILE-PROPERTIES TEST MATRIX

Group Number		Specimen Configuration	Number of Specimens								
			Conventional Process 7075-T73 Forging Thickness (in.)			Advanced Thermal/ Mechanical Treatment 7474-TMT1 Forging Thickness (in.)			Advanced Thermal/ Mechanical Treatment 7475-TMT2 Forging Thickness (in.)		
			6.7	2.0	1.0	6.7	2.0	1.0	6.7	2.0	1.0
1	Longitudinal grain	2	3	3	2	3	3	2	3	3	
2	Short-transverse grain	2	—	—	2	—	—	2	—	—	
Subtotal		4	3	3	4	3	3	4	3	3	
Subtotal		10			10			10			
Total		30									

The test-specimen configuration is shown in Figure 62 and conforms to ASTM Standard E8-61T, Reference 9, for standard tension-test round specimens.

Selected locations in each forging from which the tensile specimens were taken are shown in Appendix A.

Test Procedure

Specimens were tested using a strain rate of 0.005 inch/inch/minute up to the 0.2-percent yield offset and then straining at a rate causing failure within one minute after offset. Testing was accomplished by using a Baldwin-Wiedeman universal tensile-testing machine; stress-strain plots were recorded on a Hewlett Packard Model 7590C X-Y recorder and are presented in Appendix B.

Test Results

Test results are shown in Table 19. The data show that TMT may improve the ultimate tensile strength and the yield strength in addition to significantly increasing the ductility of the material. One 7075-T73 specimen, 0101, demonstrated a slant fracture and resulted in the low values measured for percent elongation and reduction in area shown in the table. A metallurgical examination of the specimen confirmed the suspicion that due to the location of the specimen near a corner of the forging, the grain orientation is not parallel to the long axis of the specimen.

FRACTURE-TOUGHNESS TESTS

The objective of these tests was to develop valid fracture-toughness values (K_{IC}) for thermally-mechanically treated aluminum-alloy forgings. Testing was conducted according to the guidelines of ASTM specification E399-72T¹⁰ in room-temperature air by testing standard-compact specimens.

Test-Specimen Configuration and Preparation

The fracture-toughness specimens were manufactured from blanks cut from selected locations in each forging. These locations, including serial numbers, are shown in Appendix A. The specimen configurations are shown in Figures 63 and 64.

Specimens were fatigue precracked on a universal Sonntag Model SF-1U fatigue-test machine fitted with a clevis fixture to accommodate compact specimens. All fatigue precracking was conducted at 10 Hz in air at room temperature using constant-amplitude loading within the guidelines of the specification. The specimens were observed under a 3-power microscope to assure the desired crack length.

Test Procedure and Test Setup

Fracture-toughness testing was conducted on a Vertol servocontrolled hydraulic tension-tension machine capable of ramp loading. The ramp-loading rate used corresponded to a stress-intensity rate between 30,000 and 150,000 psi $\sqrt{\text{in.}}$ per minute. Clevis fixtures required for each size compact specimen were designed and fabricated according to the guidelines of ASTM E399-72T.¹⁰

The matrix of specimens tested is shown in Table 20.

Crack opening was measured by a strain-gage-instrumented clip gage. The test data, load, and crack opening were plotted directly by a Hewlett Packard Model 7590C X-Y recorder. From each recording, the load P_Q was obtained for determining fracture toughness.

Test Results

The results of the testing are summarized in Table 21 along with pertinent data used in the analysis. The method of reducing data is in accordance with the requirements of ASTM E399-72T and is demonstrated in Figure 65. Individual load-displacement recordings for each specimen are given in Appendix C.

As indicated in Table 21, five tests resulted in valid measurements of plane-strain fracture toughness, K_{IC} . For each of the invalid measurements, the conditional fracture toughness, K_Q , and the reason for invalidity is indicated. As seen in the notes of Table 21, all specimens except one were invalid because of specimen dimensions. This indicates that a plane-strain condition cannot be achieved in the 1- and 2-inch-thick forgings. In the case of the thick (6.7-inch) forgings, the specimens must be larger in order to obtain a valid plane-strain fracture-toughness value, K_{IC} , for the longitudinal grain direction.

Significant improvements in the conditional fracture toughness of TMT aluminum-alloy forgings have been achieved for all three thicknesses investigated. Table 22 is a comparison of average results for each forging and shows the percentage improvement when compared to the commercial 7075-T73 measurements. The high conditional fracture-toughness values of the TMT forgings are further substantiated by the fact that each TMT specimen fracture shows shear lips. In particular, the longitudinal grain direction shows very large shear lips covering 20 to 50 percent of the fracture surface. Typical examples of the difference in fracture surface are shown in Figures 66, 67, and 68.

FATIGUE-STRENGTH TESTS

The fatigue-strength characteristics of a metal are of primary importance in considering the application of that material to helicopter structure. A thorough evaluation must include an analysis of the influences of stress ratio (minimum stress/maximum stress), stress concentration, grain direction, and forging thickness on fatigue properties. The testing conducted on axially loaded specimens provides the data necessary for evaluating the thermal-mechanical-treatment aluminum-alloy forgings when compared to data for similar forgings fabricated from conventional 7075-T73 aluminum alloy.

Test-Specimen Configuration

Two types of specimens, smooth and notched, were used for fatigue tests. Smooth-specimen details are shown in Figure 69. The notched specimen, Figure 70, is designed to produce a stress-concentration factor, K_T , of 3.0.

Test Procedure and Test Setup

All specimens were axially loaded using either a Wiedeman fatigue-test machine Model SF-1-U or an Amsler Vibraphore fatigue-test machine. Load frequency was 30 Hz on the SF-1-U and 70 Hz on the Vibraphore. No difference in fatigue strength was noted between specimens tested at 30 Hz and those tested at 70 Hz. Axial test loads were measured by a calibrated strain-gage link. The adapter assembly which fixed the test specimen in the machine also contains calibrated strain-gaged links to determine bending loads. The bending gages were used during specimen installation to produce an alignment which results in no bending in the specimen. During testing, all links were monitored to verify the axial load and to verify alignment of the test specimen. Strain gages were coupled to an Ellis Associates BA-12 or BA-13 bridge amplifier and total system accuracy was within ± 2 percent.

All fatigue testing was conducted in air at room temperature and at constant-amplitude load levels in groups of a minimum of eight specimens to develop the S-N curve for each of 26

combinations of test-program variables, with the objective of acquiring data over the life range from 10^4 to 5×10^7 cycles. Program variables, shown in Table 23, include material, forging thickness, grain direction, stress ratio, and stress-concentration factor.

Testing emphasized the specially treated forgings, and in particular the two-inch-thick forging, to develop the steady-stress/alternating-stress relationship (Goodman diagram) for the 7475-TMT alloy forgings.

Test Results

The objective of the fatigue testing is to demonstrate the achievement of a 20-percent increase in fatigue strength of TMT alloys when compared to 7075-T73. In many instances, that goal has been achieved or exceeded.

The results of the tests are shown in terms of fatigue-stress level and number of cycles in Figure 71 through 96. Where possible, comparisons of data for 7075-T73 groups have been made with 7475-TMT results obtained from this series of tests and are presented in Figures 97 through 108. Detailed test results are provided in Table 24. A summary of the results based on a comparison of endurance limits at 5×10^7 cycles is given in Table 25 by using test data and other sources of data for 7075-T73. Goodman diagrams for the two-inch-thick 7475-TMT1 and 7475-TMT2 aluminum-alloy forgings are presented in Figures 109 and 110 for the longitudinal grain orientation.

All specimens except two exhibited typical failure modes for smooth and notched fatigue specimens. The smooth specimens failed at the minimum section at the midlength of the specimen; the notched specimens failed at the notch. The two smooth specimens which did not follow trends failed in the threads provided for gripping the specimen in the test fixture. Because of the flat curve defined by the seven other specimens from this group, these two atypical failures are included in the statistical analysis of the data.

As demonstrated by the data, TMT1 achieved or exceeded the goal of a 20-percent increase in fatigue strength when compared to 7075-T73 for the majority of test conditions. The improvements ranged approximately from 5 percent to 75 percent and suggest that advantages can be achieved with this thermal-mechanical treatment.

The TMT2 practice achieved or exceeded the goal of a 20-percent increase in fatigue strength in two cases and is rated second to TMT1 on the basis of fatigue properties.

The impact of these results on design of helicopter structure is demonstrated by example in Appendix E.

Metallurgical examinations were conducted on a number of specimens to identify the origin of failure, the extent of fatigue damage prior to separation of the fracture surfaces, and microstructure characteristics. Hardness measurements are summarized in Table 26. As indicated in Figures 111 and 112, the origin of failure for the smooth and notched specimens selected is at the surface of the specimen. Grain orientation and grain size are shown in Figures 113 and 114. Two test specimens, 0716 shown in Figure 111 and 0714, have a slanted grain orientation which is neither longitudinal nor transverse. This is attributed to the fact that these specimens came from the edge of the one-inch-thick forging.

FATIGUE-CRACK PROPAGATION-RATE TESTS

The objective of these tests is to obtain fatigue-crack propagation-rate data over a range of stress and environmental conditions representative of those expected in the service life of helicopter hardware.

Test-Specimen Configuration and Preparation

Thirty fatigue-crack propagation-rate specimens were fabricated from blanks cut from selected locations in each forging. These locations are centered with respect to the thickness of each blank and are shown in Appendix A. The specimen configuration is shown in Figure 115.

In order to measure crack growth, a grid consisting of approximately 40 lines with a nominal spacing of 0.040 inch was photographically applied to one side of each specimen. A typical specimen with the grid is shown in Figure 116.

Test Procedure and Test Setup

Table 27 contains the matrix of test parameters for the 30 fatigue-crack and propagation-rate specimens. All testing was conducted at a load frequency of 5 Hz.

Loads were applied to the specimen as shown in Figure 116. The test setup included a load cell in series with the specimen. Load control was provided to permit no greater than ± 1.5 -percent variation of the cyclic range of load for the duration of each test. In cases where precracking loads higher than the test crack-propagation loads were required, care was taken to step down to the test loads in small increments and to let the crack grow to a length such that the prior load would not influence the crack-growth data.

Crack growth was monitored visually by observing the intersection of the crack front with the grid lines previously described. Dye penetrant (Type MIL-I-25135, spotcheck SKL-HF penetrant by Magnaflux Corporation) and optical magnification of various power (15X and 45X) were used as aids in following the crack in those specimens tested in a 3.5-percent salt solution; the optical magnification was used as an aid in following the crack. In this case, the salt solution is contained in a transparent container surrounding the crack as shown in Figure 117. The crack is viewed through the container. Periodic checks were made to insure that cracking was progressing uniformly on both sides of the specimen.

Basic crack-growth data, consisting of crack length and number of fatigue cycles, was reduced by computer to determine the fracture-mechanics parameters of stress-intensity-range factor, ΔK , and fatigue crack propagation rate, $\Delta a/\Delta N$. Data is presented in Figures 118 through 147 and tabulations including basic data can be found in Appendix D with a listing of the computer program used.

The stress-intensity range was calculated using the following expression from Reference 8:

$$\Delta K = \frac{\Delta P}{BW^{1/2}} \left[29.6 \left(\frac{a}{W} \right)^{1/2} - 185.5 \left(\frac{a}{W} \right)^{3/2} + 655.7 \left(\frac{a}{W} \right)^{5/2} - 1017.0 \left(\frac{a}{W} \right)^{7/2} + 638.9 \left(\frac{a}{W} \right)^{9/2} \right],$$

where ΔP is the load range, $P_{MAX} - P_{MIN}$,

a is average crack length,

B is average thickness of specimen, and

W is average width of specimen per Reference 8.

Test Results

The results of the fatigue-crack propagation-rate tests are presented in Figures 118 through 147 as plots of stress-intensity-factor range, ΔK , versus fatigue-crack-propagation rate, $\Delta a/\Delta N$.

In general, both TMT1 and TMT2 alloys demonstrated more favorable crack-growth rates when compared to 7075-T73. In some instances this is due to the fact that TMT alloys maintain stable crack-growth rates at the higher values of stress-intensity-range factor, ΔK ; in other instances, the crack-propagation rates of TMT alloys are slower than 7075-T73 rates. Of the two TMT alloys tested, TMT2 is rated better than TMT1 on the basis of crack-propagation rates.

The results of the short-transverse grain direction are particularly significant and demonstrate that TMT alloys are superior in performance to 7075-T73 in thick forgings.

Forging Thickness — Forging thickness may or may not influence the crack-propagation rates in TMT aluminum-alloy forgings. Referring to Table 28, one can see that the 7475-TMT2 performance is equal to or better than the 7075-T73, and is greater for the one- and two-inch-thick forgings in room-temperature air, than it is for the 6.7-inch-thick forging. The 7475-TMT1 alloy does not show room-air crack-propagation rates superior to 7075-T73 for one- and two-inch forgings, but demonstrates the advantage of stable growth rates in the 6.7-inch forging for both grain directions, something which is not possible in conventional 7075-T73 alloy at the higher values of stress-intensity-range factor, ΔK .

In a 3.5-percent salt solution, 7475-TMT1 and 7475-TMT2 demonstrate the same crack-propagation rates. As shown in Table 28, the short-transverse crack-propagation rates of TMT aluminum alloys are equivalent to 7075-T73 rates in the thick (6.7-inch) forging, and remain stable at higher values of stress-intensity-factor range, ΔK . A thickness effect is apparent in the longitudinal direction in TMT alloys; the crack-propagation rates of TMT alloys are 33 percent faster than 7075-T73 in one-inch forging and 100 percent faster in two- and 6.7-inch forging.

Environment – For each of the three materials, a 3.5-percent salt solution was found to increase the crack-growth rates above those obtained in an air environment. The crack-growth rate of 7475-TMT1 in salt solution is approximately three times the rate in air. This is also true for 7475-TMT2 and for conventional 7075-T73.

In a 3.5-percent salt solution, 7475-TMT1 and 7475-TMT2 demonstrate the same crack-propagation rates. In comparison to 7075-T73, the crack-propagation rates of TMT alloys are faster, but this is offset by the fact that TMT alloys have the capability to maintain stable crack-growth rates at high values of stress-intensity-factor range, ΔK . This cannot be achieved in conventional 7075-T73 alloy.

Grain Direction – Longitudinal and short-transverse specimens were tested from the 6.7-inch-thick forgings. In both environments, room air and 3.5-percent salt solution, no significant differences were found in the crack-growth rates of TMT material loaded parallel to the grain (longitudinal) and TMT material loaded transverse to the grain (short-transverse). This applies to both TMT1 and TMT2, and is a distinct advantage over the conventional 7075-T73 material which demonstrates short-transverse crack-growth rates 33 percent faster than longitudinal crack-growth rates (see Table 29).

Another advantage clearly identified in the results is the fact that crack-growth rates in TMT1 and TMT2 remain stable at values of stress-intensity-factor range, ΔK , where 7075-T73 crack-growth rates were unstable.

STRESS – CORROSION TESTS

Alcoa's participation in Task III of the Boeing Vertol contract consisted of evaluating the resistance to stress-corrosion cracking of the 6.7-, 2.0-, and 1.0-inch-thick 7075 and 7475 hand forgings produced at the Cleveland Plant in Task II of this contract.

Samples of 6.7-, 2.0-, and 1.00-inch-thick 7075 and 7475 hand forgings solution-heat-treated, quenched, and artificially aged 24 hours at 250°F in Task II were aged additionally 2 to 9 hours at 350°F. Longitudinal 0.125-inch-diameter threaded-end tensile specimens were machined from the T/2 location of all of the samples of forgings. Short-transverse 0.125-inch-diameter threaded-end tensile specimens were machined from the samples of 6.7- and 2.0-inch-thick forgings, and short-transverse 0.75-inch-diameter C-rings were machined from the samples of 1.0-inch-thick forgings. The specimens were stressed at 25, 35, or 45 ksi and exposed to a 3.5-percent NaCl solution by alternate immersion, Federal Method 823, for 84 days. The second-step aging times at 350°F, the stresses at which the specimens were exposed, and the results of the corrosion test are summarized in Table 30 for the 6.7-inch-thick forgings, in Table 31 for the 2.0-inch-thick forgings, and in Table 32 for the 1.00-inch-thick forgings.

Stress-corrosion acceptance criteria and minimum tensile properties are well-established for 7075-T73 products. Figure 148 demonstrated that a second-step aging of 8 hours at 350°F resulted in the 1- and 2-inch-thick 7075-T73 forgings being aged to electrical conductivities well above the specified minimum of 38 percent IACS and to yield strengths well above the guaranteed minimum of 56 ksi specified for forgings up to 3 inches thick. The 6.7-inch-thick 7075-T73 forging given a second-step aging of 8 hours at 350°F also displayed an electrical conductivity well above the specified minimum of 38 percent IACS. Figure 148 provides

some evidence that the nominal aging practice provides sufficient latitude within the specification limits for successful commercial production of 7075-T73 forgings.

Although a minimum electrical conductivity and minimum tensile properties have not been specified for 7475-T73 forgings, the multiple second-step aging times that were used in the investigation permit a comparison of the tensile properties and electrical conductivity of the 7075-T73 and the 7475-T73 forgings at comparable levels of resistance to stress corrosion. From Figures 149 and 150, it is evident that the fabrication procedures used in this investigation produced longitudinal yield strengths in the 7475-T73 forgings that were above the minimum value of 56.0 ksi specified for 7075-T73 hand forgings of thicknesses less than 3.0 inches, but that for an equivalent resistance to stress-corrosion cracking the 7475-T73 forgings had strengths lower than those of the 7075-T73 forgings included for comparison. Based on this limited data for 7475-T73 forgings, it would appear that minimum tensile properties for 7475-T73 forgings would have to be lower than those that have been specified for 7075-T73 forgings. Furthermore, Figure 151 shows that the minimum electrical conductivity of 38 percent IACS will not be applicable to 7475-T73 forgings fabricated by the studied procedures. The 7475-T73 forgings require aging to higher electrical conductivities to obtain the same resistance to stress corrosion that 7075-T73 forgings display at an electrical conductivity of 38 percent IACS.

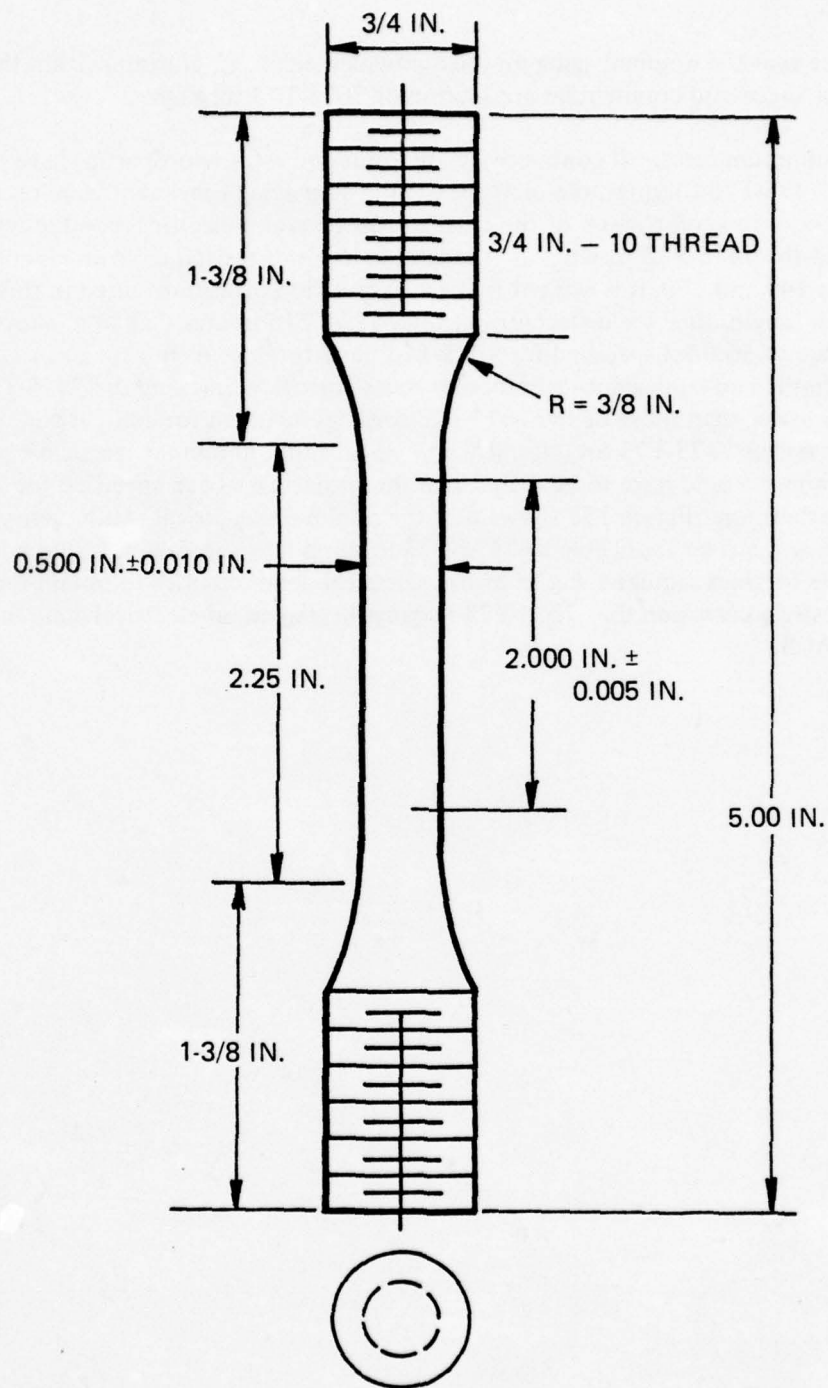
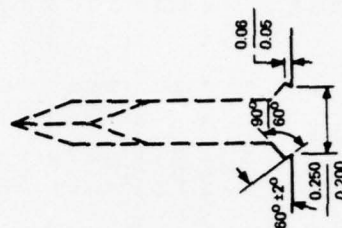
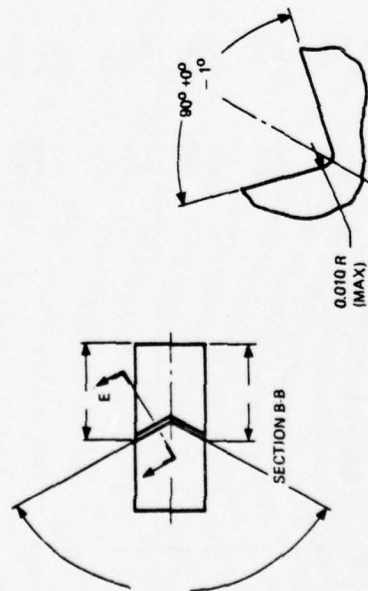


Figure 62. Configuration of Standard Round Specimen for Tension Test.

TABLE 19. MECHANICAL PROPERTIES FOR TASK II FORGINGS, THERMAL/MECHANICAL HEAT-TREATED ALUMINUM ALLOY

Material	Forging Thickness (in.)	Grain Orientation	Specimen Number	Diameter (in.)	Area (sq in.)	Gage Length (in.)	Yield Load (lb)	Yield Stress (psi)	Ultimate Load (lb)	Ultimate Stress (psi)	Elongation (%)	Reduction in Area (%)
7075-T73	1	L	0101*	0.500	0.1964	2	12,750*	64,918*	14,650*	74,592*	6*	9*
			0102	0.500	0.1964	2	12,625	64,282	14,650	74,592	13	23
			0111	0.499	0.1956	2	12,500	63,905	14,700	75,153	14	36
	2	L	0201	0.500	0.1964	2	11,800	60,081	14,500	73,828	13	34
			0202	0.500	0.1964	2	11,875	60,463	14,400	73,319	13	29
			0211	0.500	0.1964	2	11,800	60,081	14,300	72,810	13	34
	6.7	S-T	0402	0.500	0.1964	2	11,700	59,572	13,400	68,228	4	5
			0403	0.500	0.1964	2	11,800	60,081	13,800	70,264	5	5
			0601	0.500	0.1964	2	11,625	59,190	13,800	70,264	13	33
			0609	0.500	0.1964	2	11,475	58,426	13,600	69,246	14	34
7475-TMT1	1	L	0701	0.500	0.1964	2	12,200	62,118	14,200	72,301	19	54
			0702	0.500	0.1964	2	12,260	62,118	14,300	72,810	16	44
			0711	0.498	0.1948	2	12,125	62,243	14,150	72,638	18	54
	2	L	0827	0.498	0.1948	2	12,000	61,601	14,250	73,151	15	46
			0828	0.499	0.1956	2	11,500	58,793	13,750	70,296	17	44
			0829	0.499	0.1956	2	11,875	60,710	14,100	72,085	17	40
	6.7	S-T	1002	0.499	0.1956	2	12,250	62,627	14,000	71,574	5	7
			1003	0.500	0.1964	2	11,700	59,572	13,700	69,755	11	23
			1201	0.499	0.1956	2	12,375	63,266	14,400	73,619	17	47
			1209	0.499	0.1956	2	12,300	62,883	14,300	73,108	17	45
7475-TMT2	1	L	1301	0.500	0.1964	2	12,000	61,099	14,150	72,046	15	55
			1302	0.499	0.1956	2	11,750	60,071	14,050	71,830	17	52
			1311	0.500	0.1964	2	11,925	60,717	14,050	71,537	17	55
	2	L	1427	0.500	0.1964	2	11,425	58,172	13,800	70,264	15	51
			1428	0.499	0.1956	2	12,000	61,349	14,000	71,574	17	47
			1429	0.500	0.1964	2	11,375	51,917	13,650	69,501	17	48
	6.7	S-T	1602	0.500	0.1964	2	12,100	61,608	14,050	71,537	14	25
			1603	0.500	0.1964	2	12,250	62,372	14,350	73,065	14	15
			1801	0.500	0.1964	2	12,400	63,136	14,400	73,319	17	44
			1809	0.500	0.1964	2	12,250	62,372	14,300	72,810	17	47

*Metallurgical examination of specimen revealed grain direction not parallel to axis of specimen.



1. FINISH ON ALL SURFACES EXCEPT AS NOTED.
2. SURFACES MARKED "A" TO BE PERPENDICULAR AND PARALLEL AS APPLICABLE TO WITHIN 0.005 IN. TIR.
3. POINTS OF INTERSECTION OF THE CRACK STARTER TIPS WITH THE TWO SPECIMEN FACES SHALL BE EQUAL DISTANCE FROM EITHER PIN-HOLE CENTER TO WITHIN 0.0125 IN.
4. DIMENSIONS "C" AND "D" MUST BE WITHIN 0.0250 IN. OF EACH OTHER. EACH OF THE TWO PARALLEL NOTCH SURFACES MUST LIE IN ONE PLANE TO WITHIN 0.0125 IN. AND MUST BE PERPENDICULAR OR PARALLEL AS APPLICABLE TO THE SPECIMEN FACES TO WITHIN 0.0125 IN.
- 5.
6. ALL DIMENSIONS IN INCHES.
7. INTEGRAL KNIFE-EDGE DETAILS.
- 8.

Figure 63. Configuration of Compact Specimen for Fracture-Toughness Testing, Specimens 0223, 0224, 0823, 0824, 1423, 1424, 0401, 1001, 1601, 0606, 1206, and 1806.



1. 32 FINISH ON ALL SURFACES EXCEPT AS NOTED.
2. SURFACES MARKED "A" TO BE PERPENDICULAR AND PARALLEL AS APPLICABLE TO WITHIN 0.004 IN. TIR.
3. POINTS OF INTERSECTION OF THE CRACK STARTER TIPS WITH THE TWO SPECIMEN FACES SHALL BE EQUAL DISTANCE FROM EITHER PIN-HOLE CENTER TO WITHIN 0.010 IN.
4. DIMENSIONS "C" AND "D" MUST BE WITHIN 0.020 IN. OF EACH OTHER.
5. EACH OF THE TWO PARALLEL NOTCH SURFACES MUST LIE IN ONE PLANE TO WITHIN 0.010 IN. AND MUST BE PERPENDICULAR OR PARALLEL AS APPLICABLE TO THE SPECIMEN FACES TO WITHIN 0.010 IN.
6. ALL DIMENSIONS IN INCHES.
7. INTEGRAL KNIFE EDGE DETAILS.

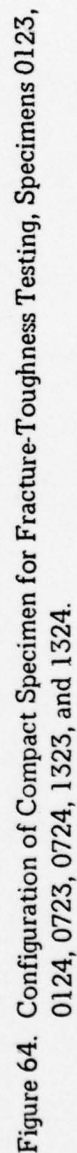


TABLE 20. FRACTURE-TOUGHNESS TEST MATRIX

Test Parameters		Number of Specimens						
		Conventional Process 7075-T73		Mechanical Treatment 7475-TMT1		Mechanical Treatment 7475-TMT2		
Group Number	Specimen Grain Direction	Test Environment	Forging Thickness (in.)		Forging Thickness (in.)		Forging Thickness (in.)	
			6.7	2.0	1.0	6.7		2.0
1	Longitudinal	70°F Air	1	2	2	1	2	2
2	Short transverse	70°F Air	1	—	—	1	—	—
Subtotal			2	2	2	2	2	2
Subtotal			6		6		6	
Total			18					

TABLE 21. FRACTURE-TOUGHNESS-TEST RESULTS FOR TASK II FORGINGS, THERMAL/MECHANICAL HEAT-TREATED ALUMINUM ALLOY

Material	Forging Thickness (in.)	Grain Orientation	Specimen Number	B (in.)	W (in.)	Fatigue Crack Length, a (in.)				P _Q (lb)	K _Q (ksi √in.)	K _{IC} (ksi √in.)	Comments
						a ₁	a ₂	a ₃	a _{av}				
7075-T73	1	L	0123	1.0023	2.0015	1.1315	1.2015	1.1615	1.1648	—	—	—	Failed in precracking
			0124	0.9753	2.0096	1.2276	1.2346	1.2096	1.2239	3,151	—	31.838	
	2	L	0223	1.25006	2.4900	1.3400	1.3800	1.3700	1.3633	8,531	48.454	—	1
			0224	1.2512	2.5029	1.3129	1.3129	1.2929	1.3062	8,582	44.612	—	1
6.7		S-T	0401	1.2511	2.4983	1.2783	1.2983	1.2683	1.2816	4,884	—	24.688	
		L	0606	1.2505	2.5030	1.2385	1.2585	1.2485	1.2485	8,614	41.816	—	1
7475-TMT1	1	L	0723	1.0026	1.9981	0.6540	0.9040	0.6440	0.7340	9,922	47.760	—	2
			0724	1.0023	1.9952	0.6835	0.9035	0.7035	0.7635	12,330	55.327	—	1
	2	L	0853	1.2520	2.4942	1.1242	1.3842	1.1342	1.2142	9,137	42.604	—	3
			0854	1.2519	2.4779	1.1179	1.3279	1.0879	1.1779	8,684	—	39.178	
6.7		S-T	1001	1.2506	2.4905	1.1005	1.3005	1.1305	1.1805	7,299	33.194	—	
		L	1206	1.2525	2.4960	1.1589	1.1939	1.1339	1.1622	10,873	47.686	—	1
7475-TMT2	1	L	1323	1.0030	2.0104	0.9635	1.1335	0.9835	1.0235	6,167	42.962	—	1
			1324	1.0028	2.0002	0.9695	1.1195	0.9895	1.0295	8,356	59.415	—	1
	2	L	1453	1.2503	2.4843	1.1495	1.2525	1.1395	1.1828	10,697	48.598	—	1
			1454	1.2512	2.4897	1.1287	1.2637	1.1287	1.1737	11,905	53.522	—	1
6.7		S-T	1601	1.2518	2.4995	1.1275	1.3175	1.1175	1.1875	8,080	—	36.535	
		L	1806	1.2506	2.4970	1.0738	1.2538	1.1138	1.1471	10,420	45.003	—	1

NOTES: 1. Specimen dimensions too small for plane-strain fracture-toughness measurement, $2.5(K_Q/a_{YS})^2 > B$ and $> a$.

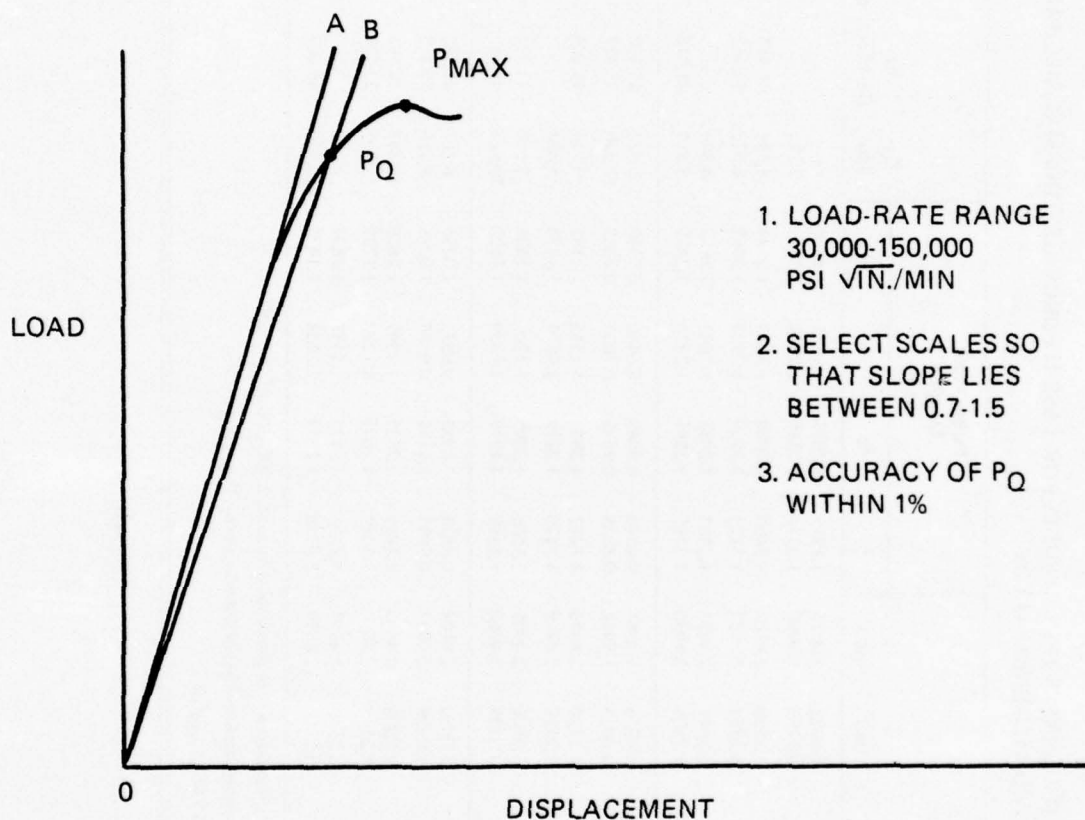
2. Specimen dimensions too small for plane-strain fracture-toughness measurement, $P_{MAX}/P_Q > 1.10$.

3. Specimen crack too short for valid test, $2.5(K_Q/a_{YS})^2 > a$.

FRACTURE TOUGHNESS TEST SPECIMEN NO. _____

LINE OA TANGENT TO INITIAL
LOAD-DISPLACEMENT CURVE

TANGENT OB = 0.95 TANGENT OA



1. LOAD-RATE RANGE
30,000-150,000
PSI $\sqrt{\text{IN.}}/\text{MIN}$

2. SELECT SCALES SO
THAT SLOPE LIES
BETWEEN 0.7-1.5

3. ACCURACY OF P_Q
WITHIN 1%

$$K_Q = \frac{P_Q}{B\sqrt{W}} \left[29.6 \left(\frac{a}{W} \right)^{1/2} - 185.5 \left(\frac{a}{W} \right)^{3/2} + 655.7 \left(\frac{a}{W} \right)^{5/2} - 1017 \left(\frac{a}{W} \right)^{7/2} + 638.9 \left(\frac{a}{W} \right)^{9/2} \right]$$

B = AVERAGE THICKNESS OF SPECIMEN
W = AVERAGE DIMENSION PER ASTM 399-72
a = AVERAGE CRACK LENGTH
 K_Q = CONDITIONAL FRACTURE TOUGHNESS

Figure 65. Method for Determining Fracture Toughness.

TABLE 22. IMPROVEMENT IN FRACTURE TOUGHNESS RELATIVE TO 7075-T73

Material and Configuration	K_Q or K_{IC} (ksi $\sqrt{\text{in.}}$)	Improvement (%)
7475-TMT1		
1 in. thick longitudinal	51.5	62
2 in. thick longitudinal	39.2	None
6.7 in. thick longitudinal	47.7	11
6.7 in. thick short transverse	33.2	34
7475-TMT2		
1 in. thick longitudinal	51.2	61
2 in. thick longitudinal	51.1	10
6.7 in. thick longitudinal	45.0	8
6.7 in. thick short transverse	36.5	48
7075-T73		
1 in. thick longitudinal	31.8	—
2 in. thick longitudinal	46.5	—
6.7 in. thick longitudinal	41.8	—
6.7 in. short transverse	24.7	—

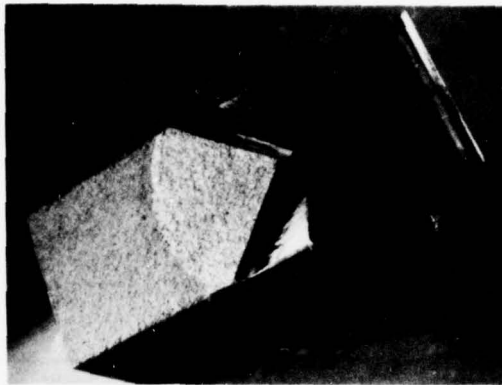


Figure 66. Fracture Surface of 7075-T73 Toughness Specimen 0124.



Figure 67. Fracture Surface of 7475-TMT1 Toughness Specimen 0724.

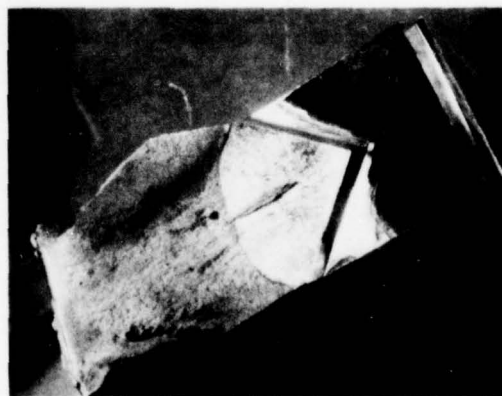


Figure 68. Fracture Surface of 7475-TMT2 Toughness Specimen 1324.

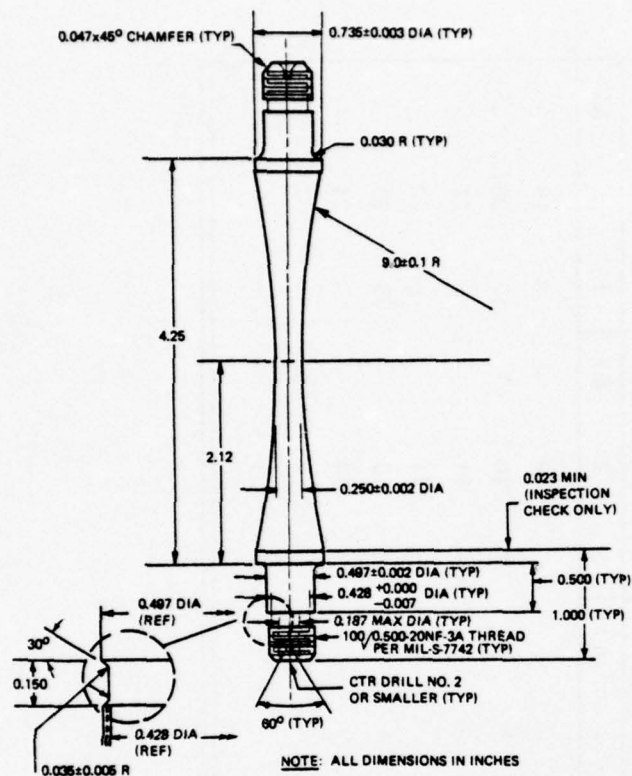


Figure 69. Configuration of Smooth Specimen for Goodman Fatigue Test.

Figure 70. Configuration of Notched Specimen for Goodman Fatigue Test.

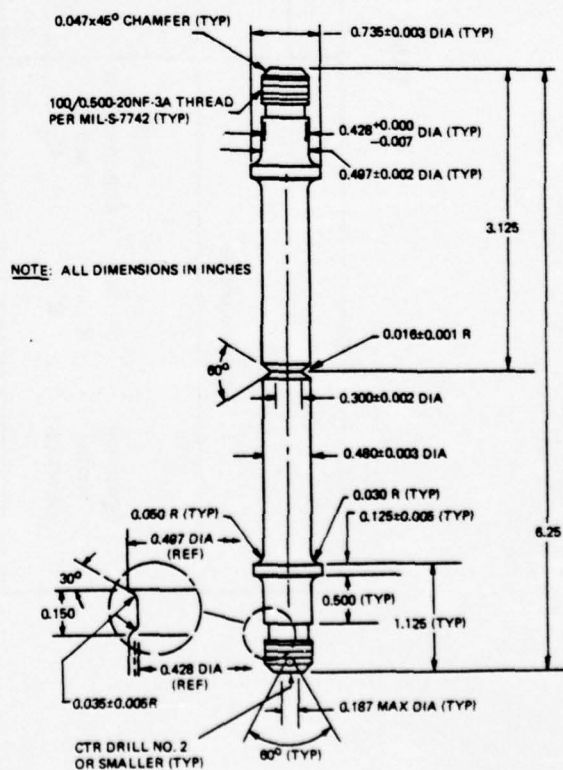


TABLE 23. FATIGUE TESTS

Test Parameters			Specimen Group Number											
			Conventional Process 7075-T73 Forging Thickness (in.)						Advanced Thermal/Mechanical Treatment 7475-TMT1 Forging Thickness (in.)					
Specimen Grain Direction	Stress Ratio, R	Stress Concentration Factor, K_T	1	2	6.7	1	2	6.7	1	2	6.7	1	2	6.7
Longitudinal	- 1.0	1.0	-	-	-	-	9	-	-	19	-	-	-	-
Longitudinal	+ 0.05	1.0	1	3	5	7	10	15	17	20	25	-	-	-
Longitudinal	+ 0.50	1.0	-	-	-	-	11	-	-	21	-	-	-	-
Longitudinal	- 1.0	3.0	-	-	-	-	12	-	-	22	-	-	-	-
Longitudinal	+ 0.05	3.0	2	4	-	8	13	-	18	23	-	-	-	-
Longitudinal	+ 0.50	3.0	-	-	-	-	14	-	-	24	-	-	-	-
Short transverse	+ 0.05	1.0	-	-	6	-	-	16	-	-	26	-	-	-
Short transverse	+ 0.05	3.0	-	-	-	-	-	-	-	-	-	-	-	-

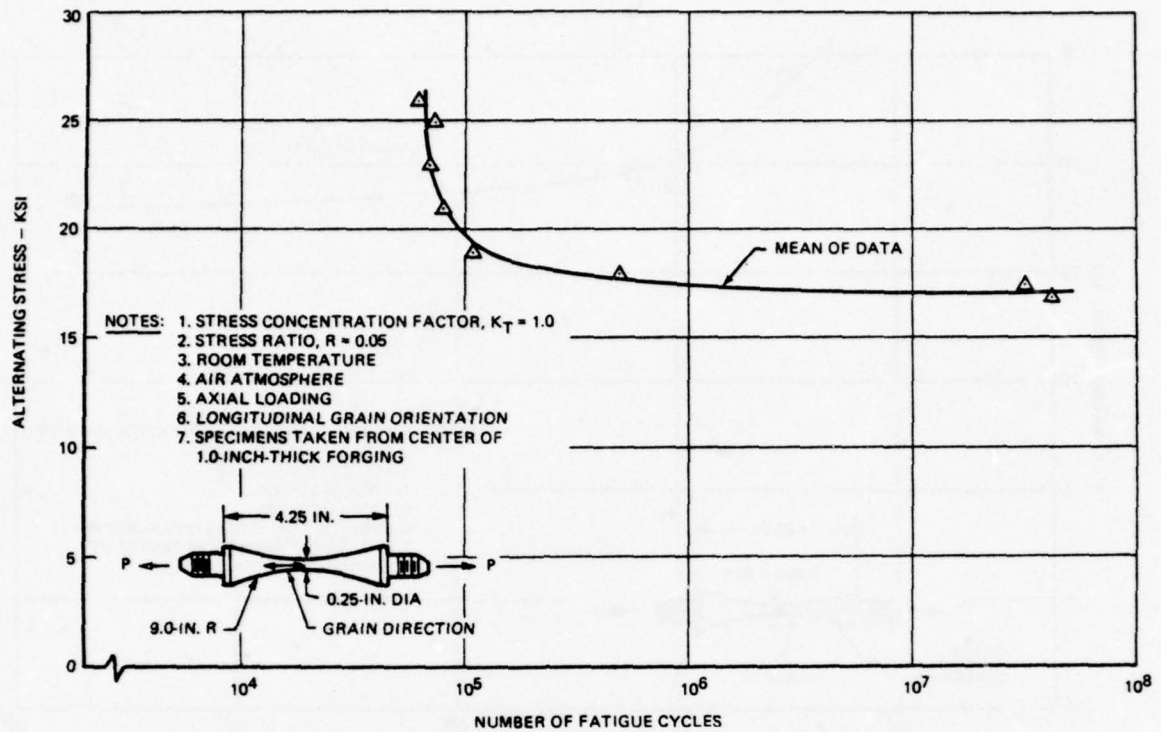


Figure 71. Fatigue Performance of Task II 7075-T73 Aluminum-Alloy Forging, Specimen Group 1.

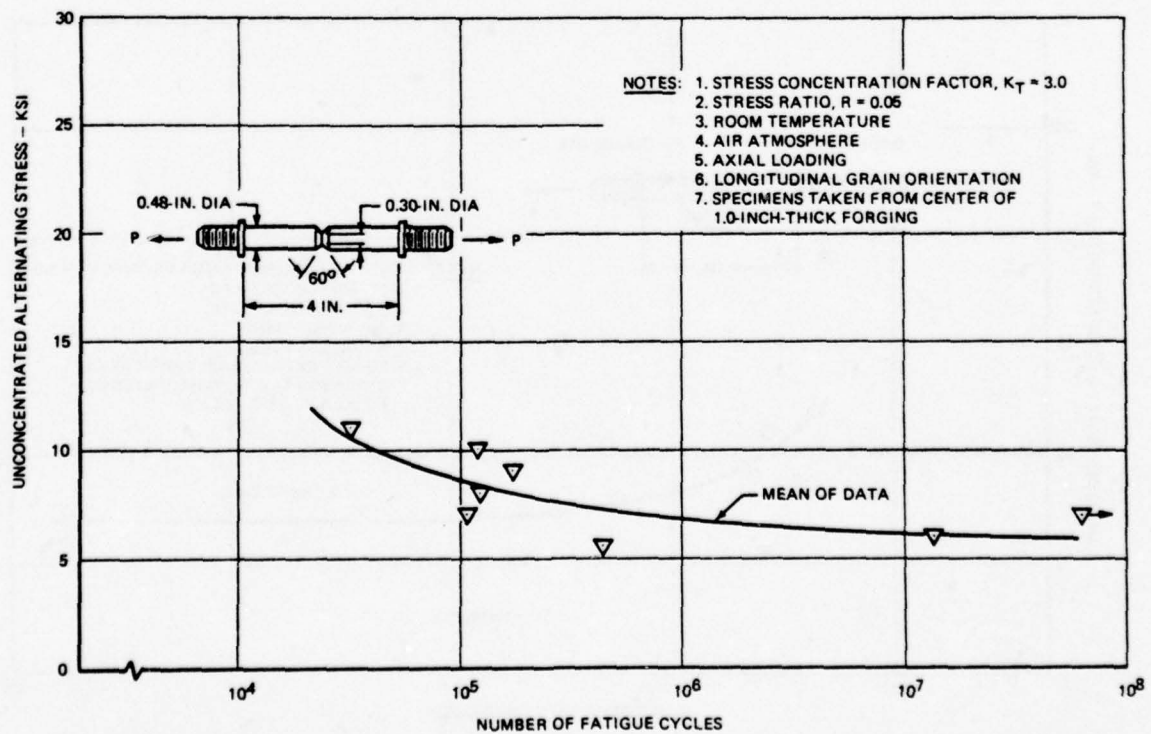


Figure 72. Fatigue Performance of Task II 7075-T73 Aluminum-Alloy Forging, Specimen Group 2.

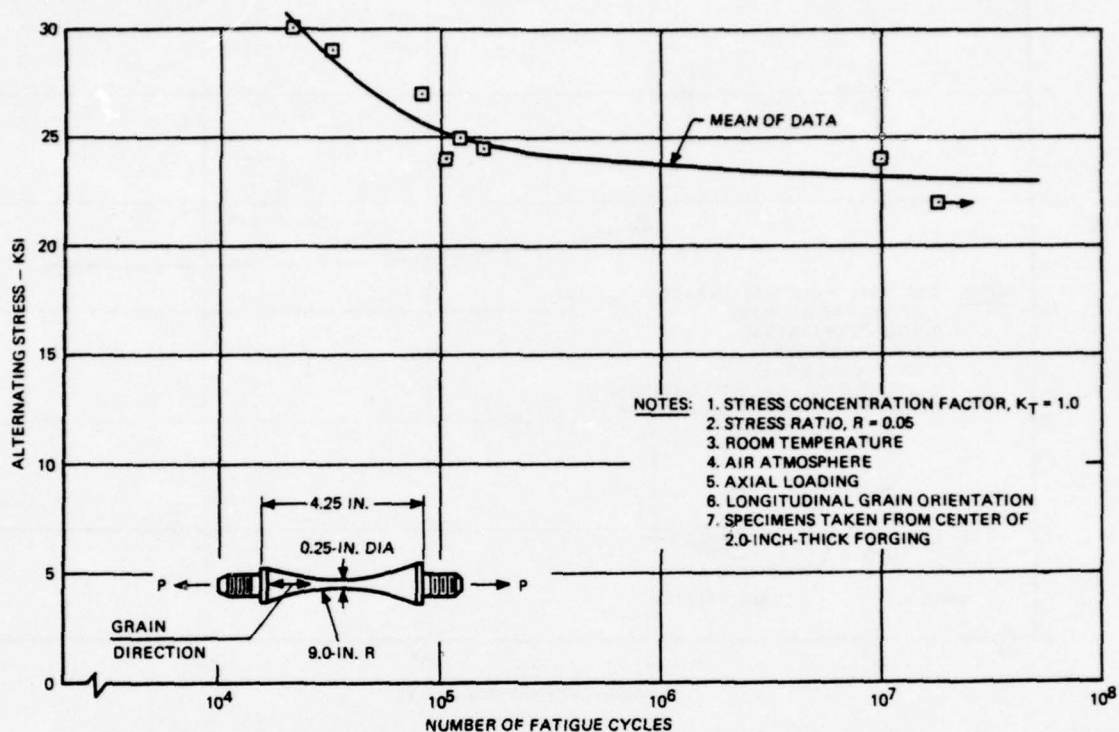


Figure 73. Fatigue Performance of Task II 7075-T73 Aluminum-Alloy Forging, Specimen Group 3.

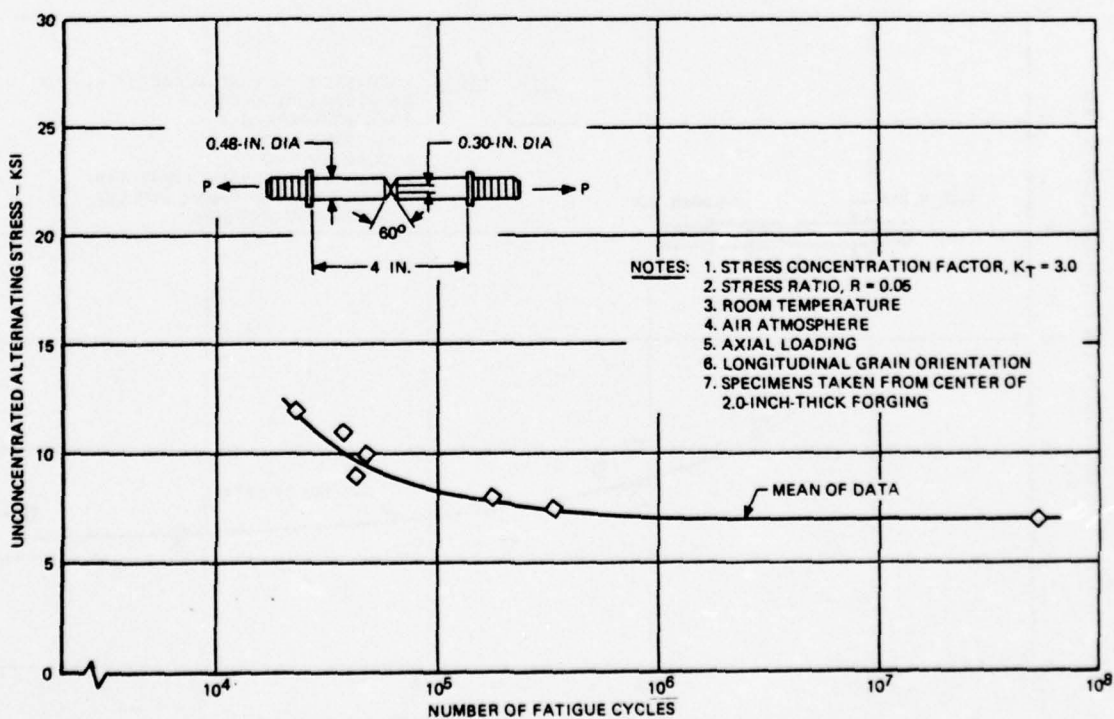


Figure 74. Fatigue Performance of Task II 7075-T73 Aluminum-Alloy Forging, Specimen Group 4.

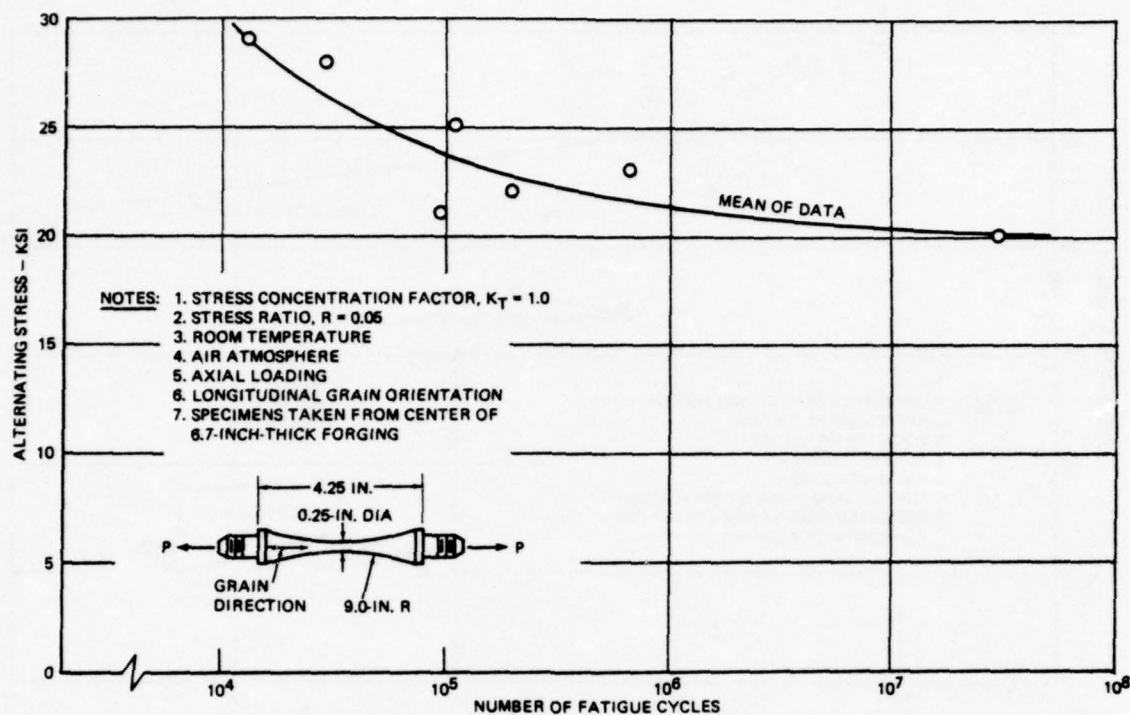


Figure 75. Fatigue Performance of Task II 7075-T73 Aluminum-Alloy Forging, Specimen Group 5.

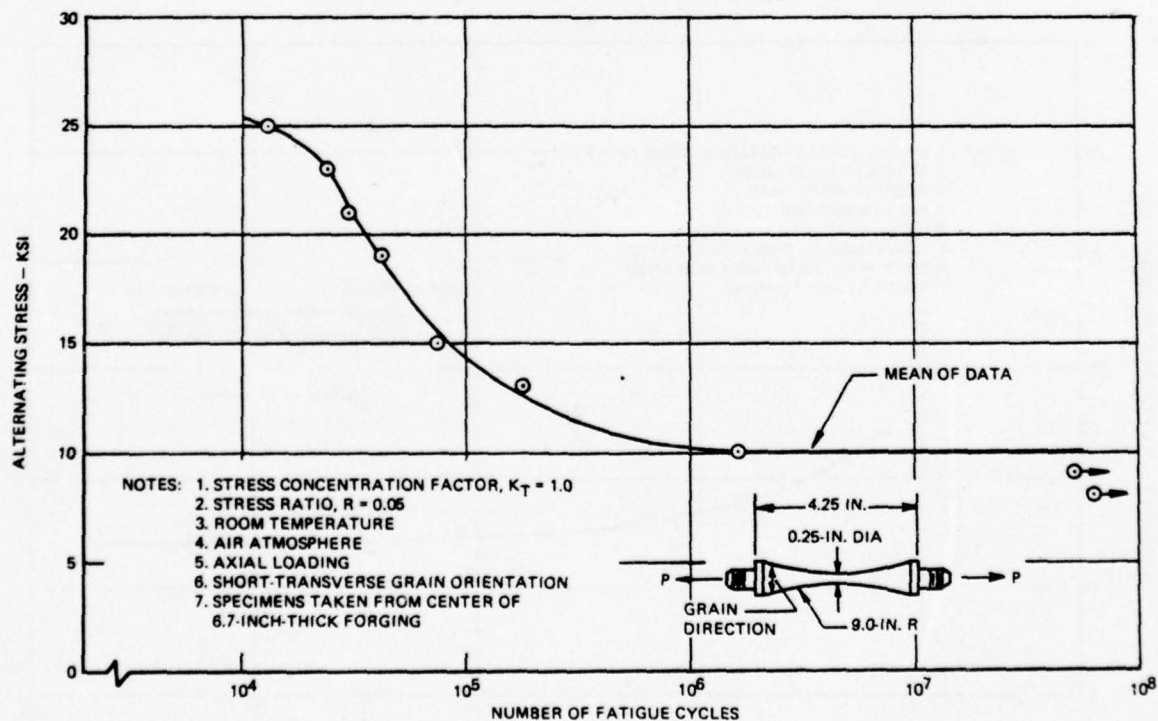


Figure 76. Fatigue Performance of Task II 7075-T73 Aluminum-Alloy Forging, Specimen Group 6.

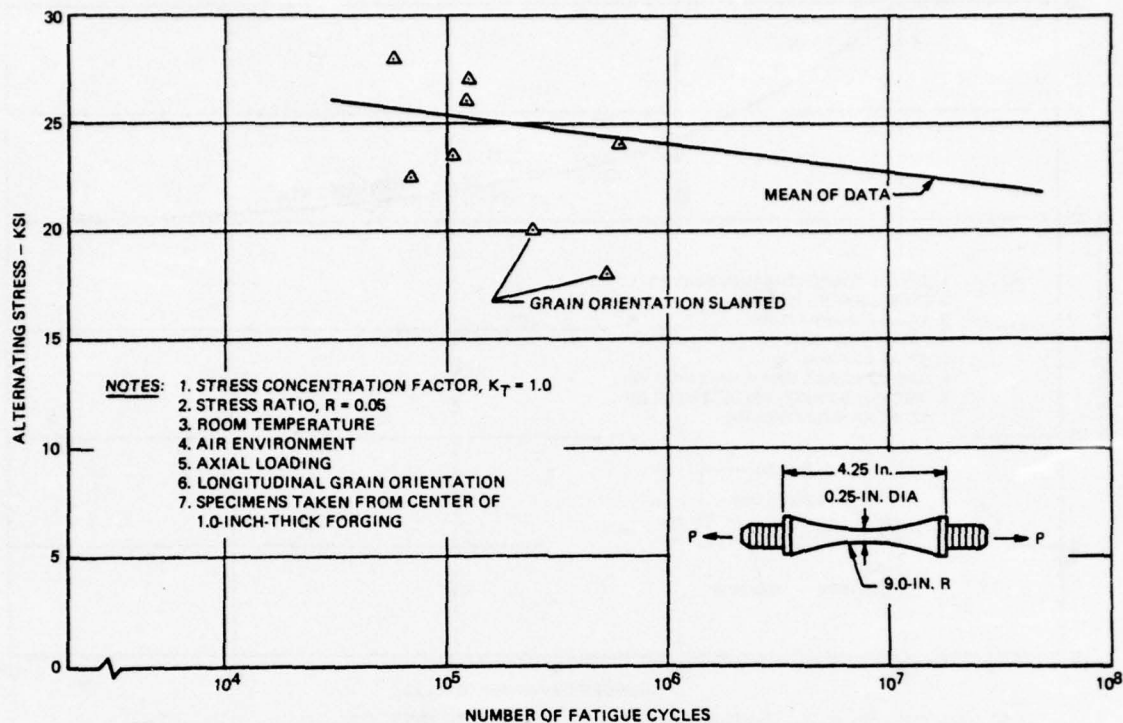


Figure 77. Fatigue Performance of Task II 7475-TMT1 Aluminum-Alloy Forging, Specimen Group 7.

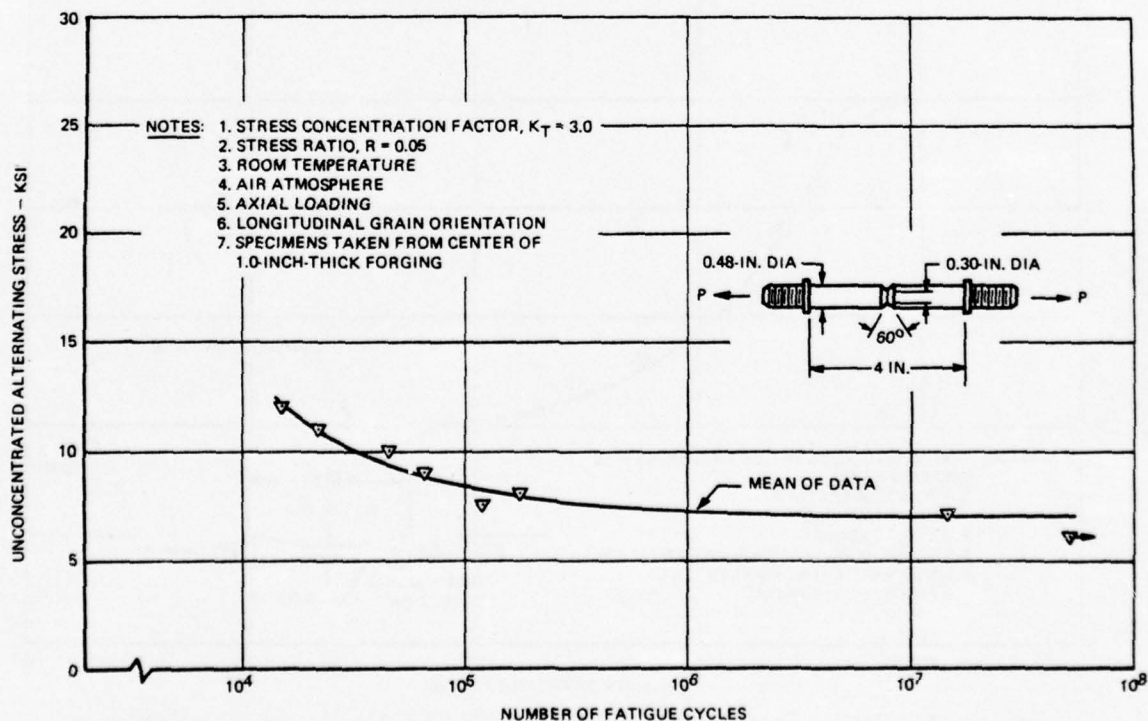


Figure 78. Fatigue Performance of Task II 7475-TMT1 Aluminum-Alloy Forging, Specimen Group 8.

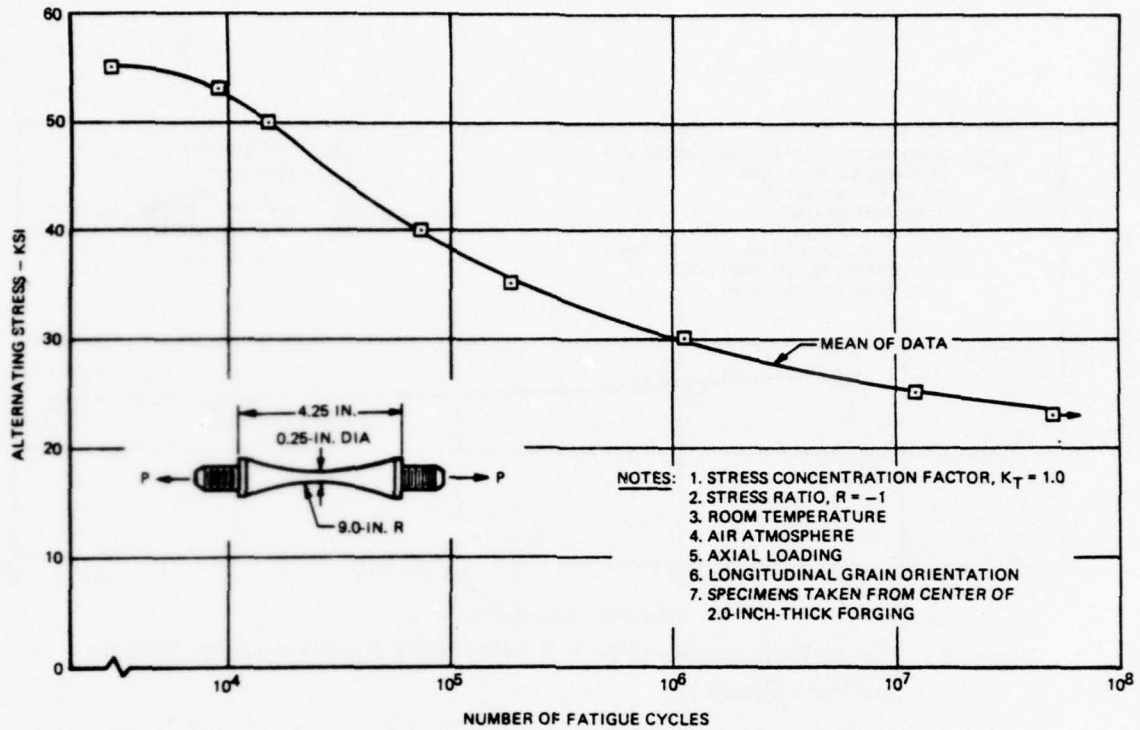


Figure 79. Fatigue Performance of Task II 7475-TMT1 Aluminum-Alloy Forging, Specimen Group 9.

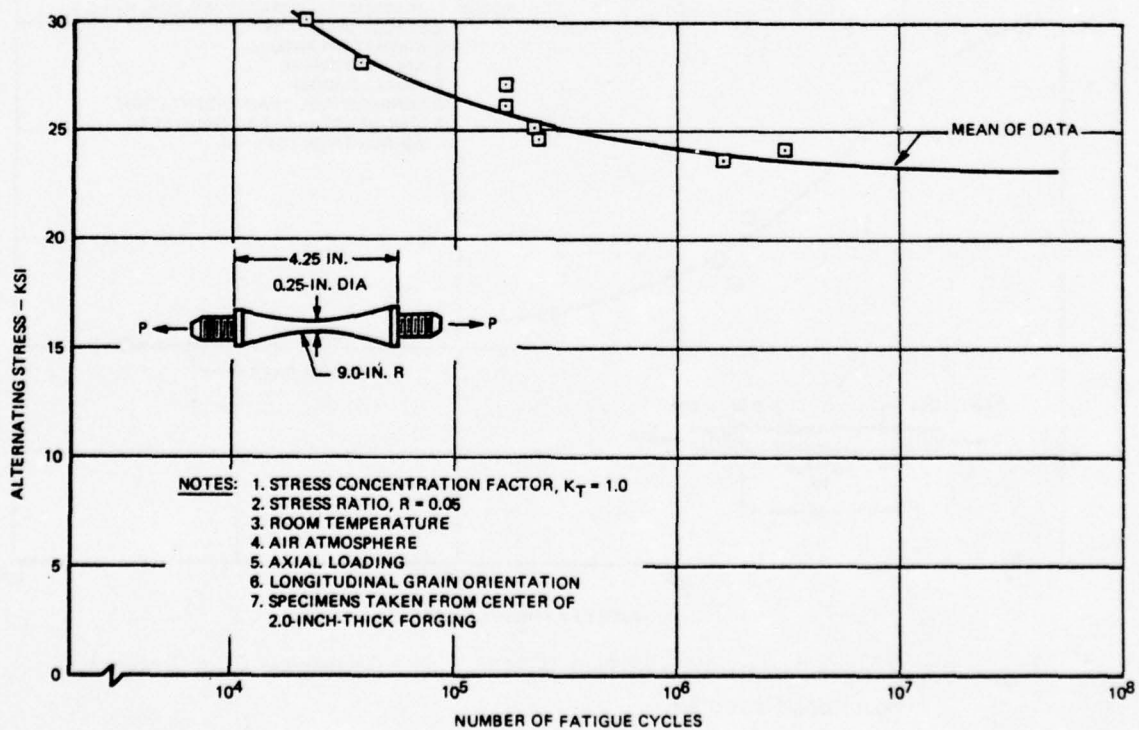


Figure 80. Fatigue Performance of Task II 7475-TMT1 Aluminum-Alloy Forging, Specimen Group 10.

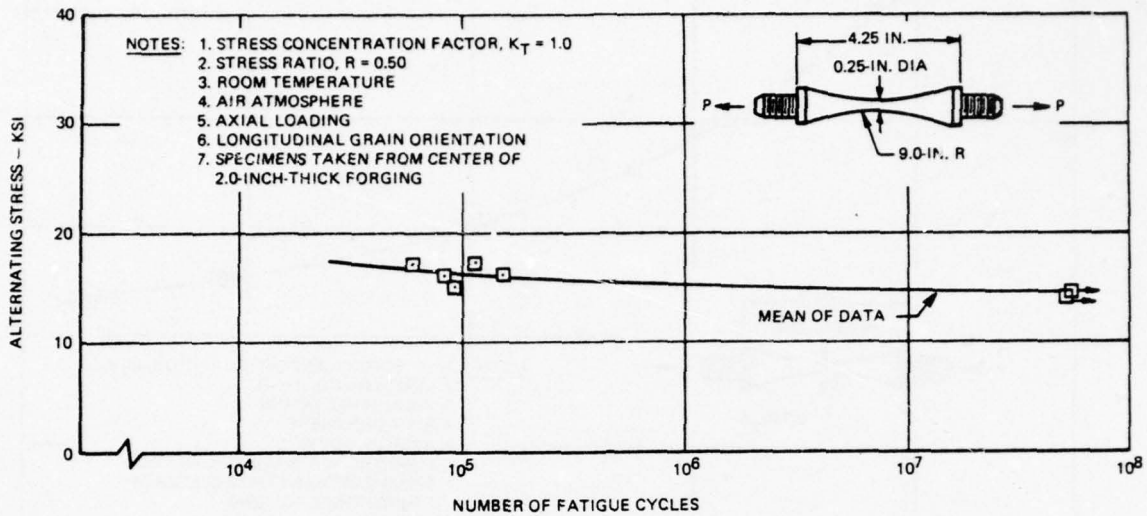


Figure 81. Fatigue Performance of Task II 7475-TMT1 Aluminum-Alloy Forging, Specimen Group 11.

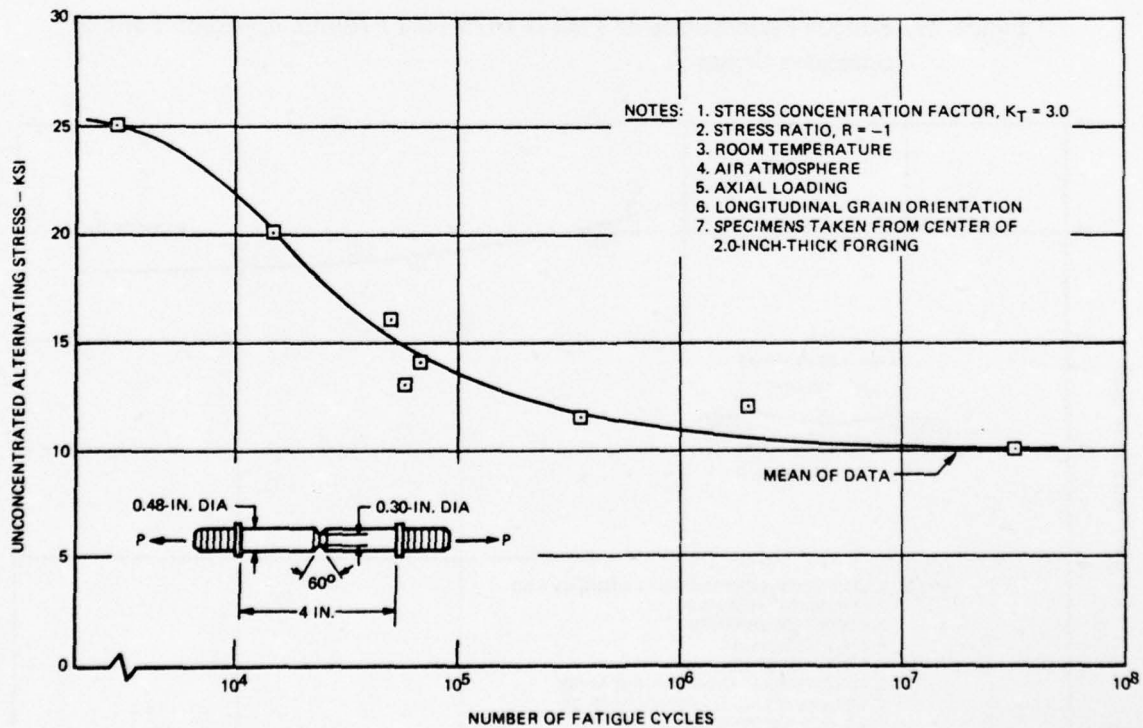


Figure 82. Fatigue Performance of Task II 7475-TMT1 Aluminum-Alloy Forging, Specimen Group 12.

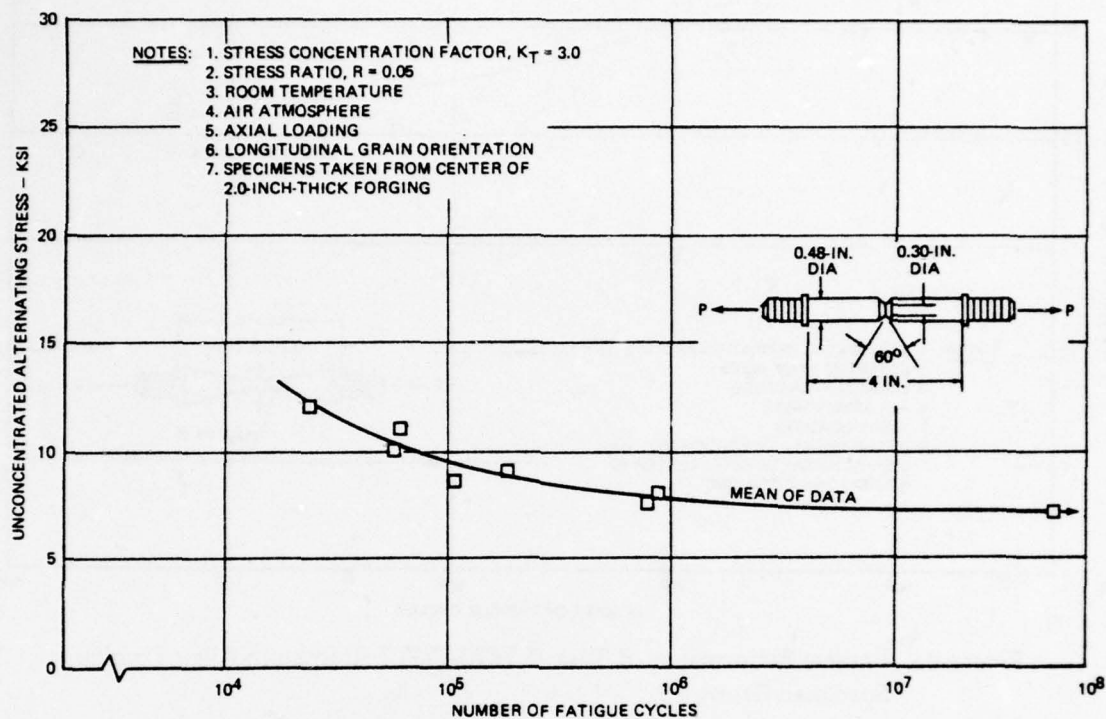


Figure 83. Fatigue Performance of Task II 7475-TMT1 Aluminum-Alloy Forging, Specimen Group 13.

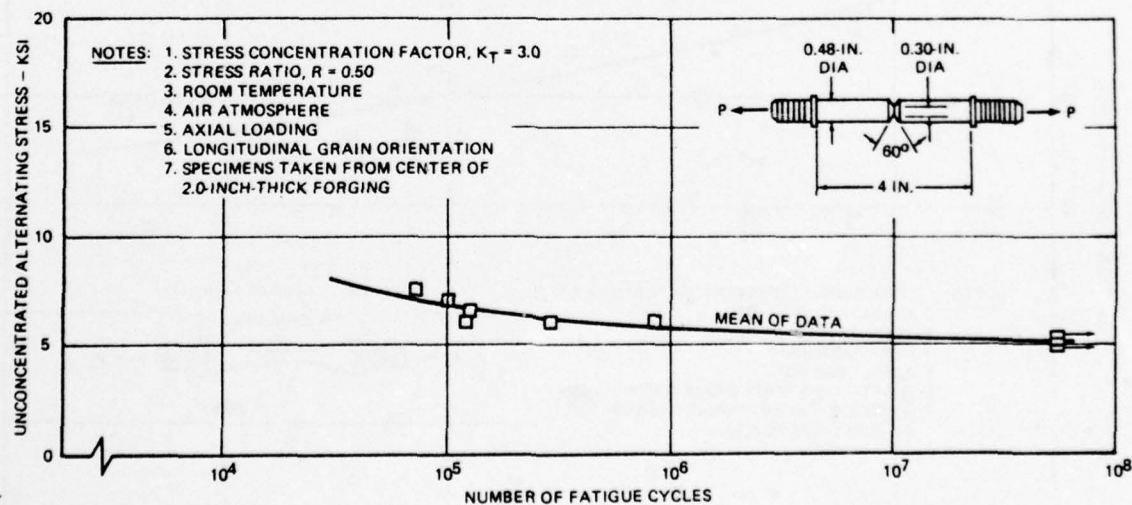


Figure 84. Fatigue Performance of Task II 7475-TMT1 Aluminum-Alloy Forging, Specimen Group 14.

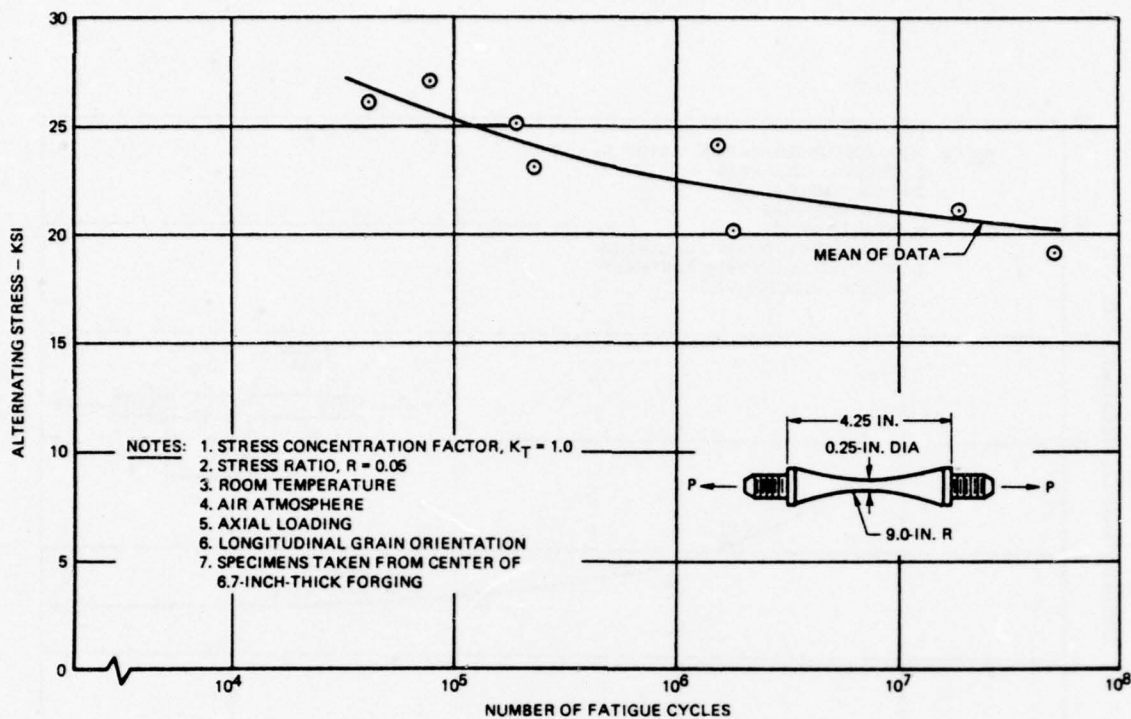


Figure 85. Fatigue Performance of Task II 7475-TMT1 Aluminum-Alloy Forging, Specimen Group 15.

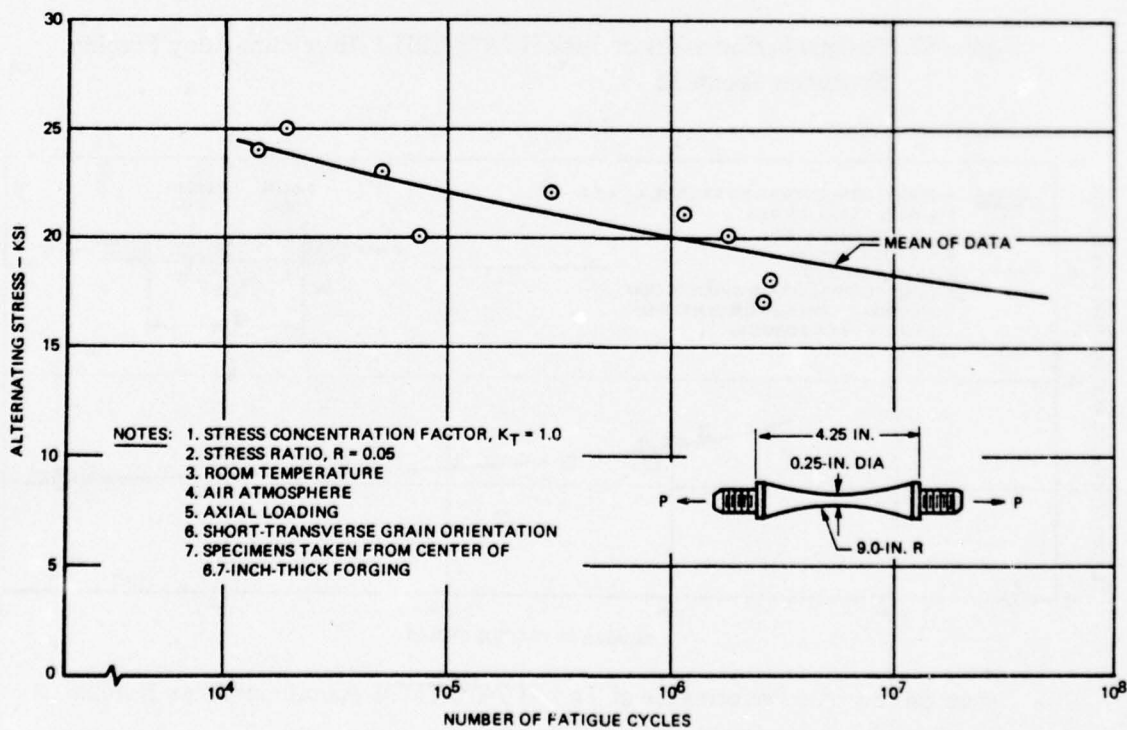


Figure 86. Fatigue Performance of Task II 7475-TMT1 Aluminum-Alloy Forging, Specimen Group 16.

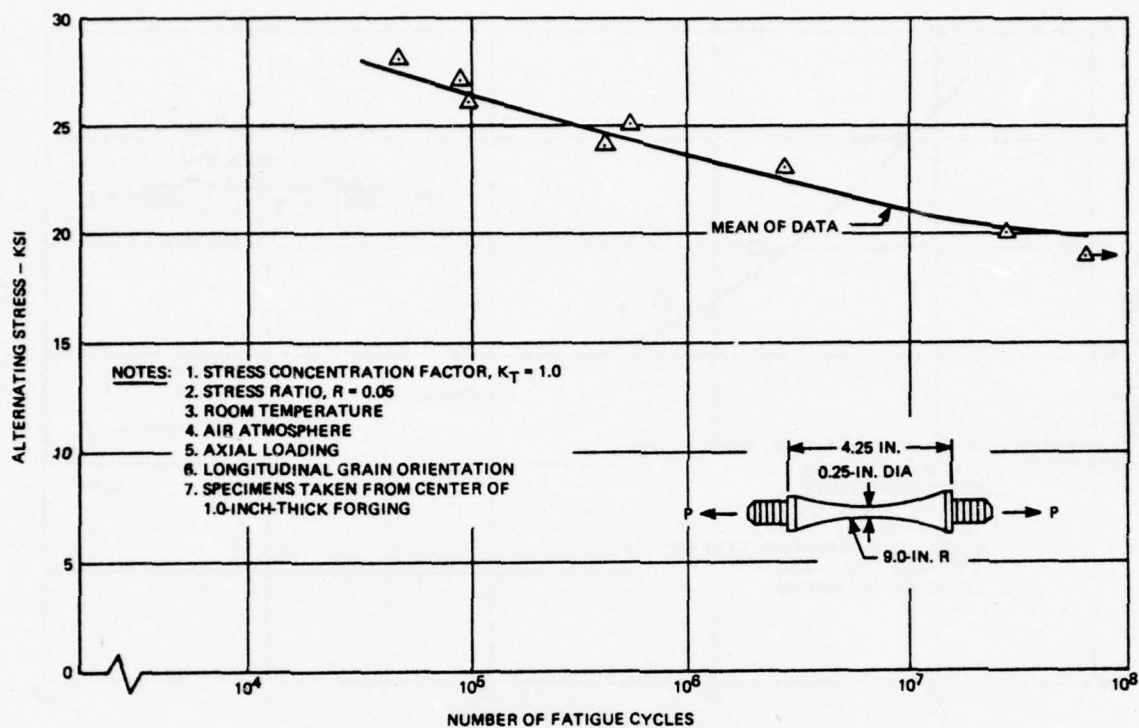


Figure 87. Fatigue Performance of Task II 7475-TMT2 Aluminum-Alloy Forging, Specimen Group 17.

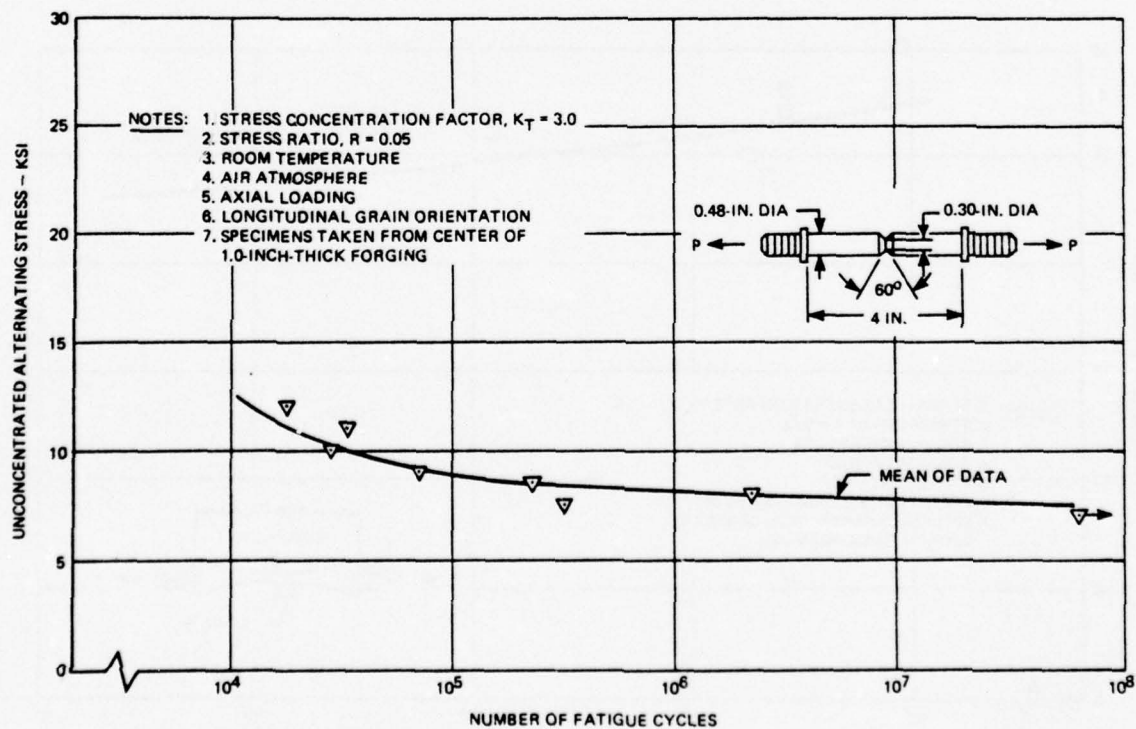


Figure 88. Fatigue Performance of Task II 7475-TMT2 Aluminum-Alloy Forging, Specimen Group 18.

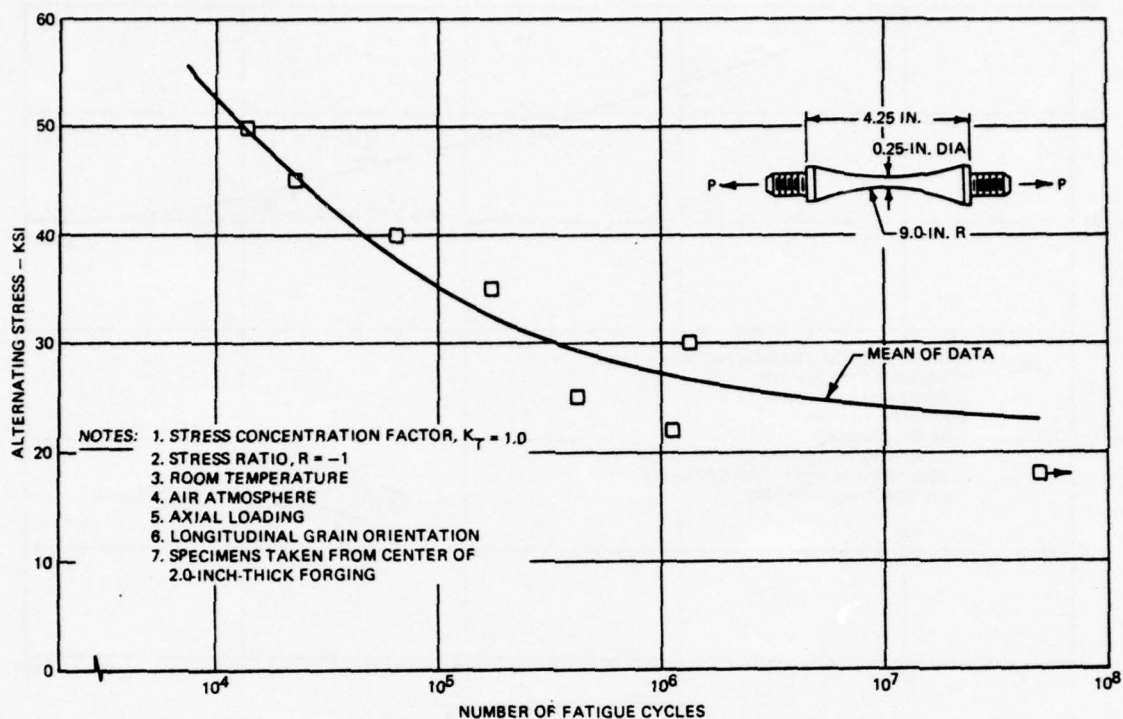


Figure 89. Fatigue Performance of Task II 7475-TMT2 Aluminum-Alloy Forging, Specimen Group 19.

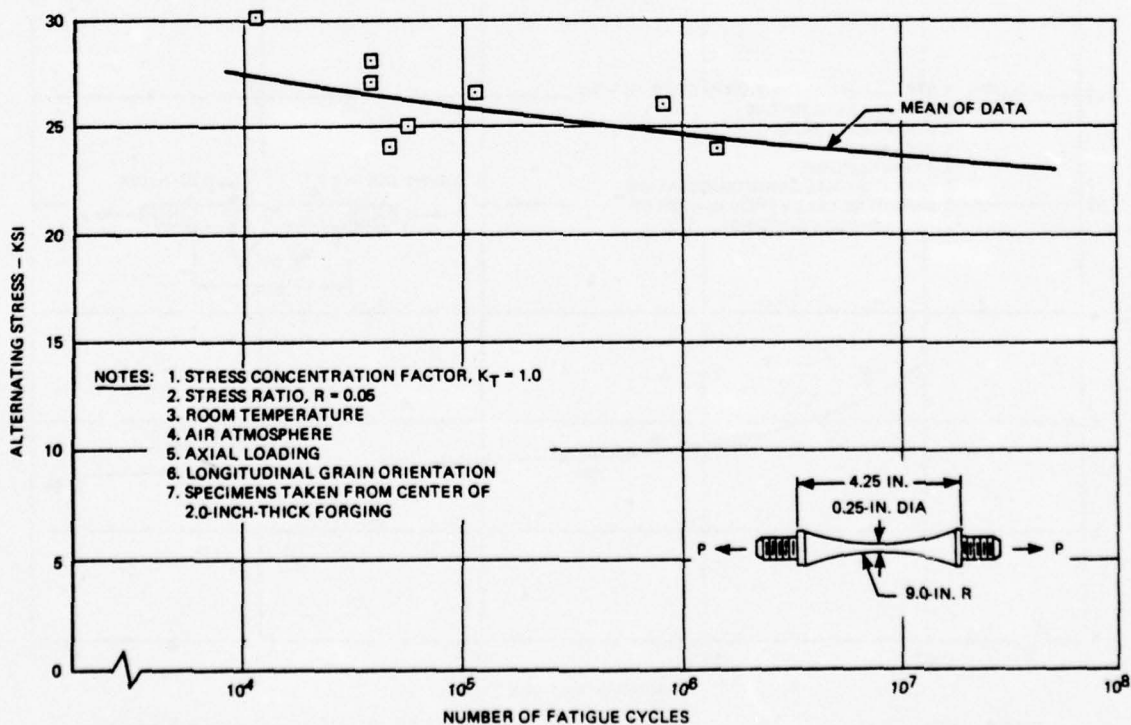


Figure 90. Fatigue Performance of Task II 7475-TMT2 Aluminum-Alloy Forging, Specimen Group 20.

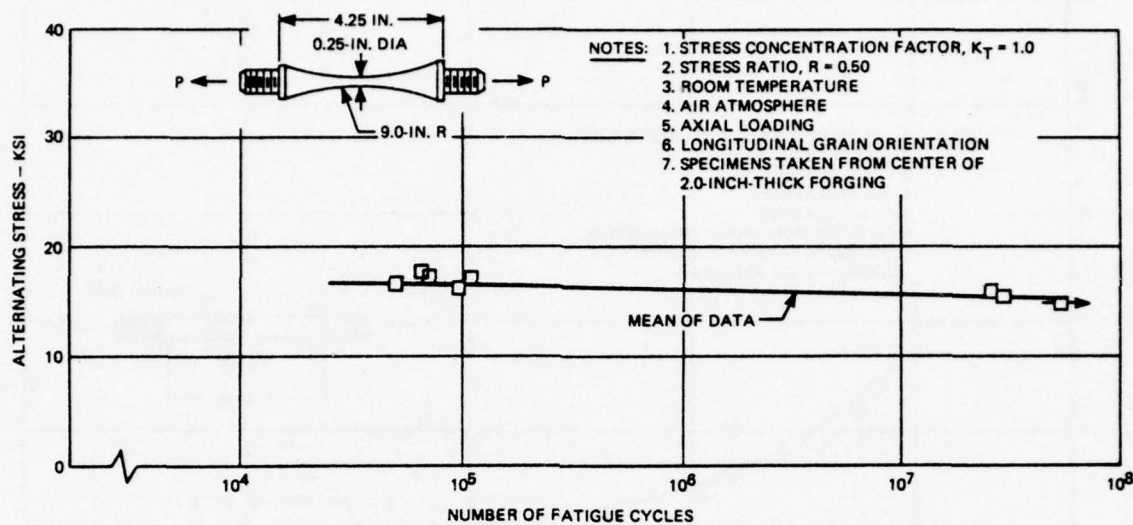


Figure 91. Fatigue Performance of Task II 7475-TMT2 Aluminum-Alloy Forging, Specimen Group 21.

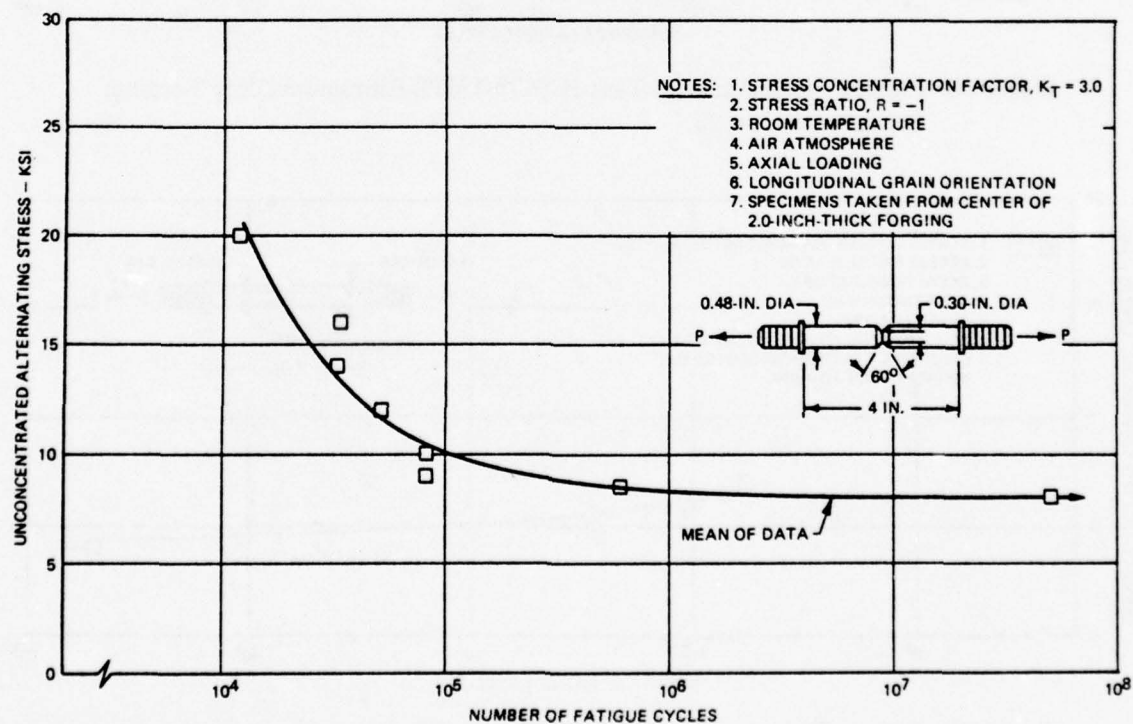


Figure 92. Fatigue Performance of Task II 7475-TMT2 Aluminum-Alloy Forging, Specimen Group 22.

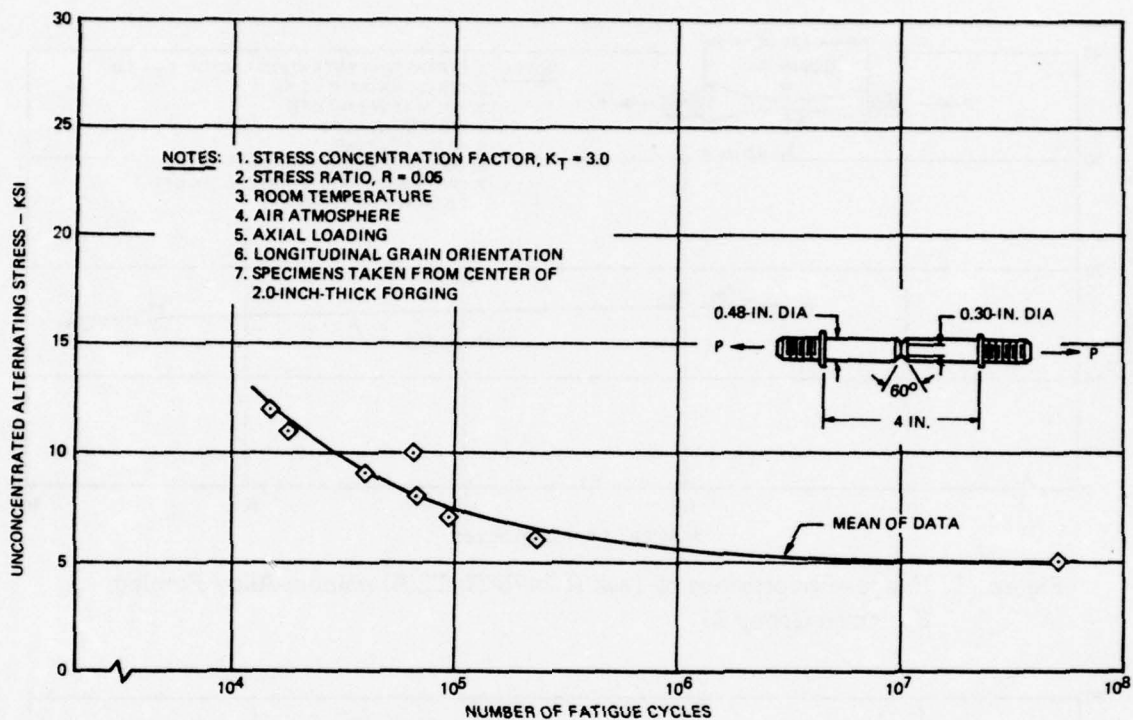


Figure 93. Fatigue Performance of Task II 7475-TMT2 Aluminum-Alloy Forging, Specimen Group 23.

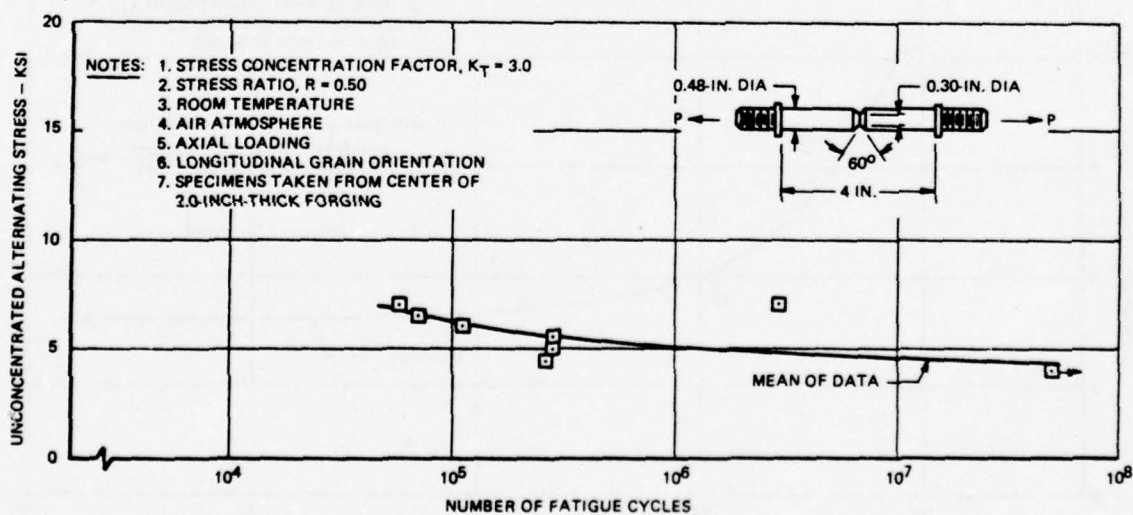


Figure 94. Fatigue Performance of Task II 7475-TMT2 Aluminum-Alloy Forging, Specimen Group 24.

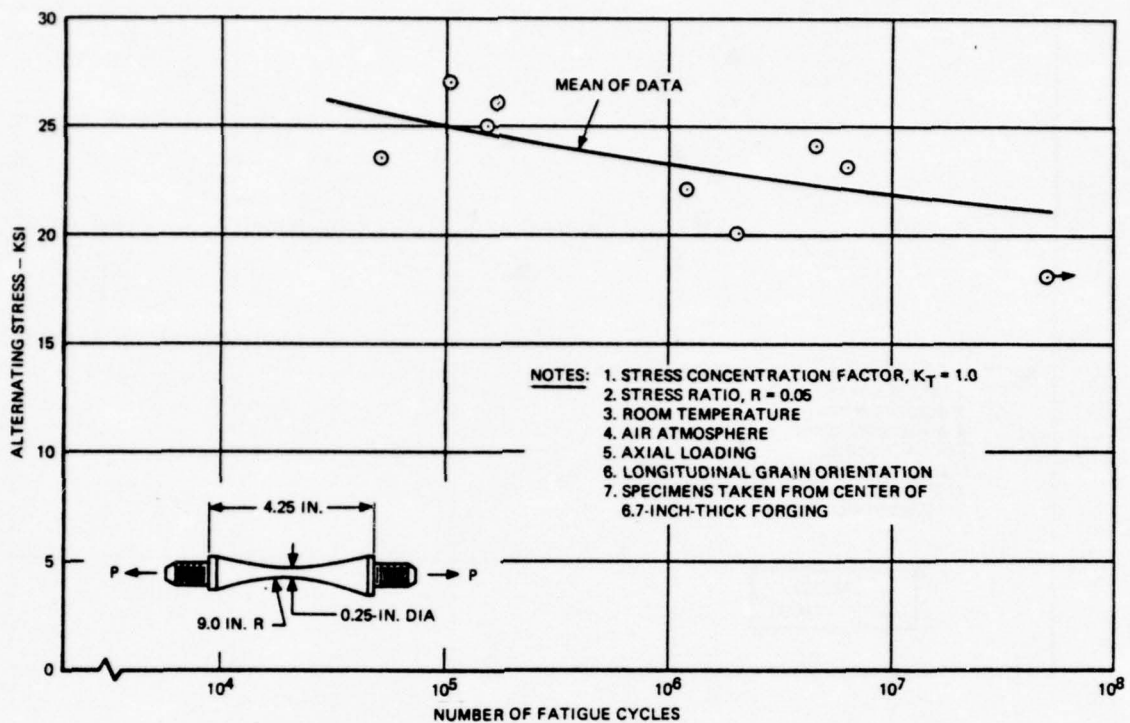


Figure 95. Fatigue Performance of Task II 7475-TMT2 Aluminum-Alloy Forging, Specimen Group 25.

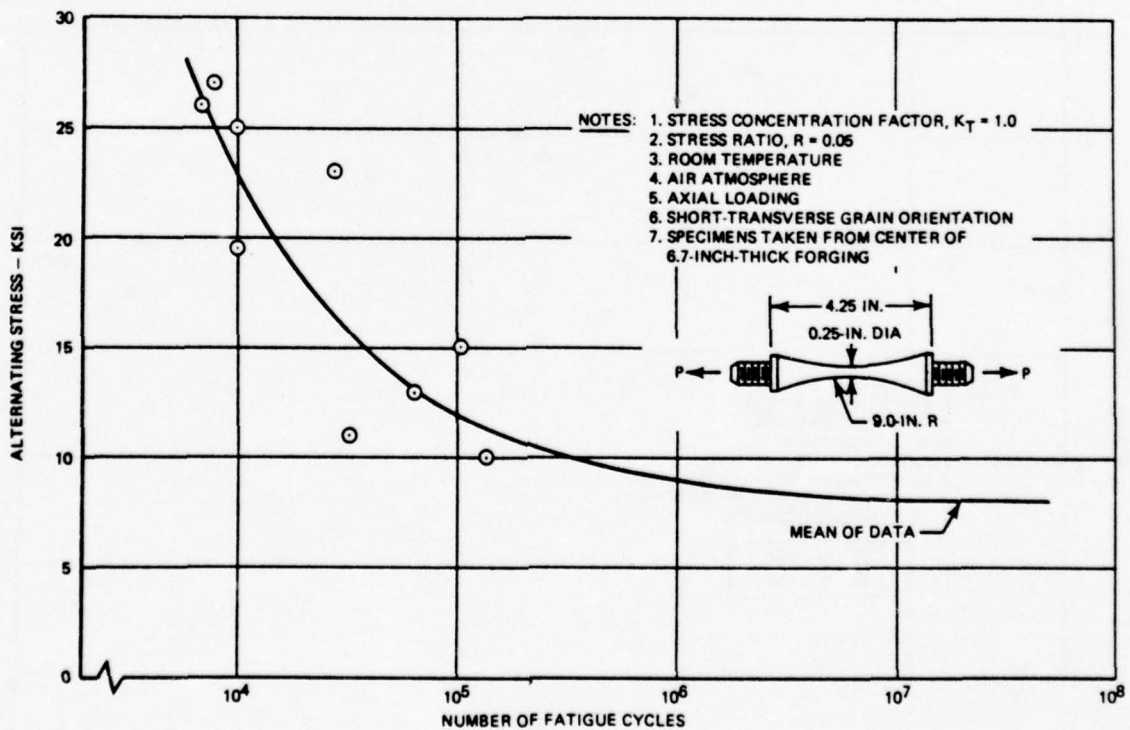


Figure 96. Fatigue Performance of Task II 7475-TMT2 Aluminum-Alloy Forging, Specimen Group 26.

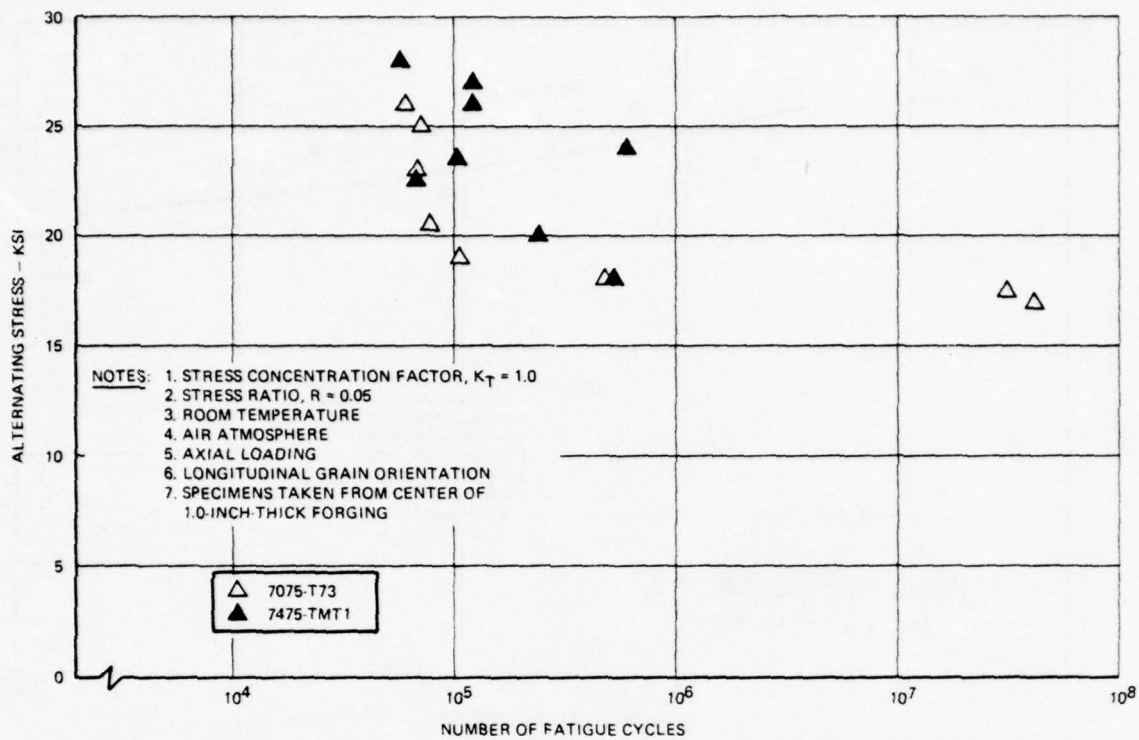


Figure 97. Comparison of Fatigue Strengths for 7075-T73 and 7475-TMT1 Forging, Groups 1 and 7.

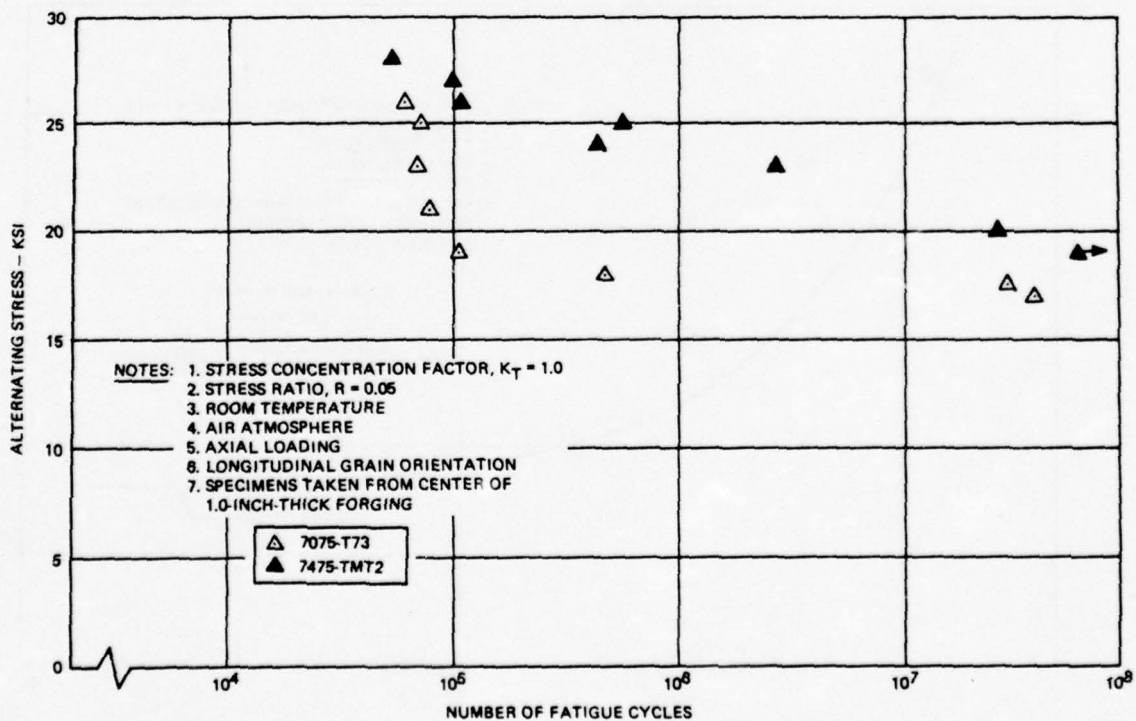


Figure 98. Comparison of Fatigue Strengths for 7075-T73 and 7475-TMT2 Forging, Groups 1 and 17.

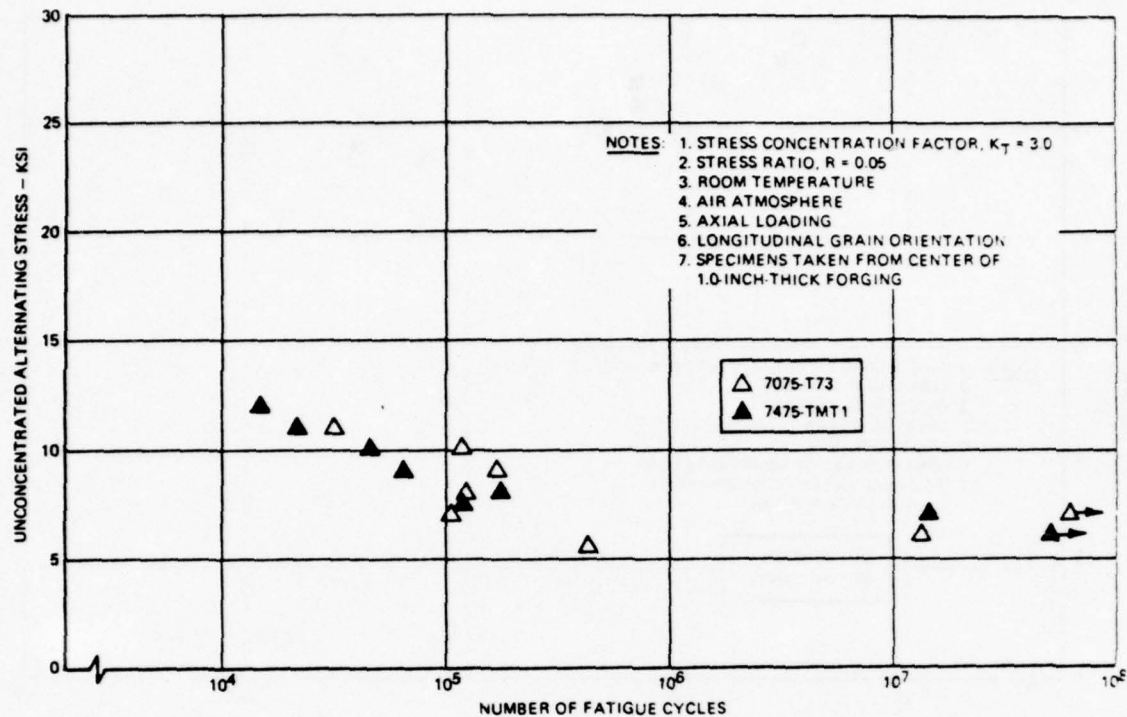


Figure 99. Comparison of Fatigue Strengths for 7075-T73 and 7475-TMT1 Forging, Groups 2 and 8.

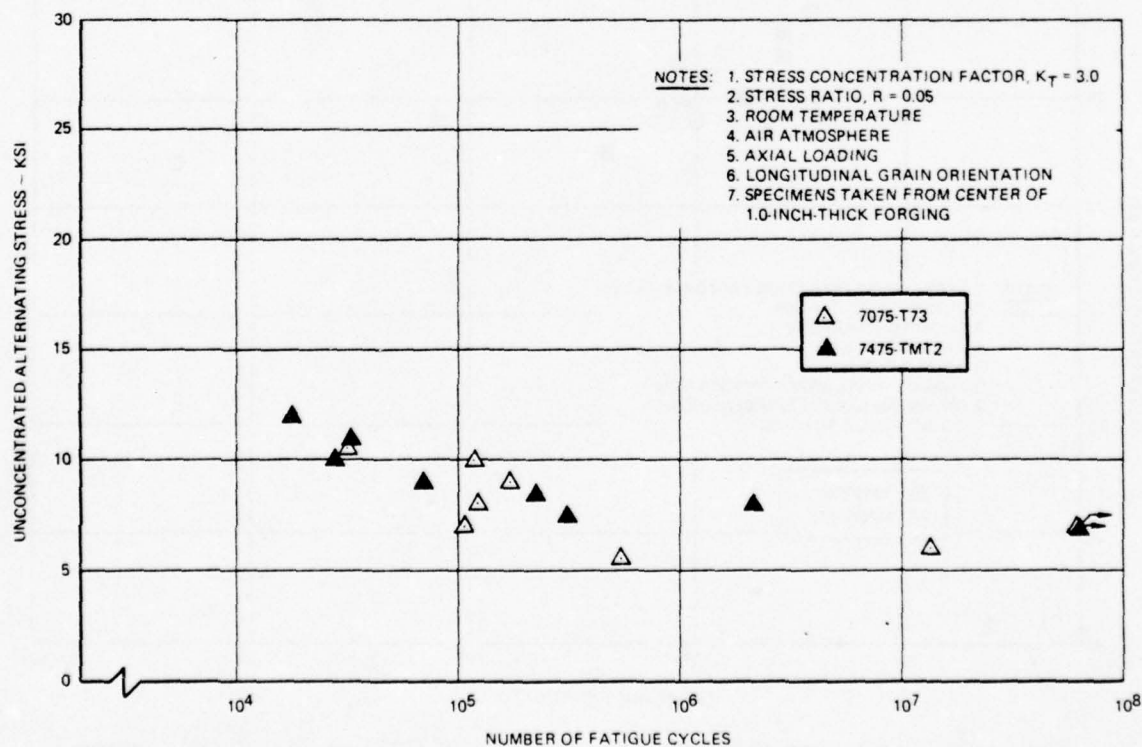


Figure 100. Comparison of Fatigue Strengths for 7075-T73 and 7475-TMT2 Forging, Groups 2 and 18.

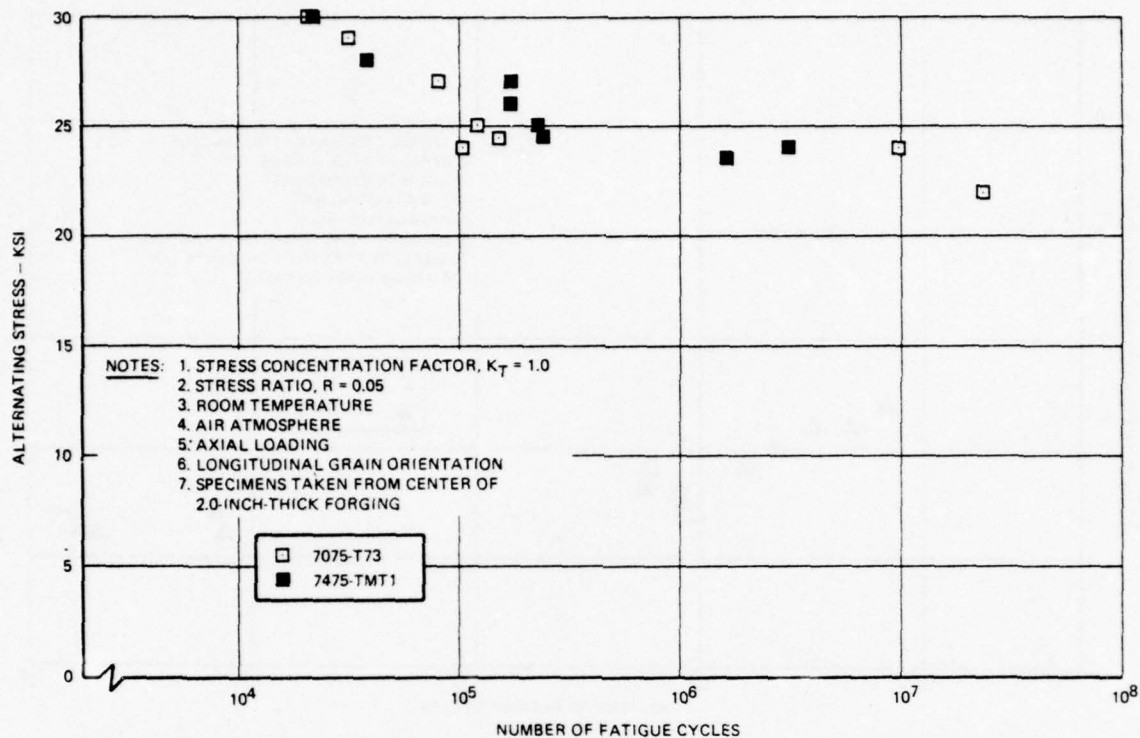


Figure 101. Comparison of Fatigue Strengths for 7075-T73 and 7475-TMT1 Forging, Groups 3 and 10.

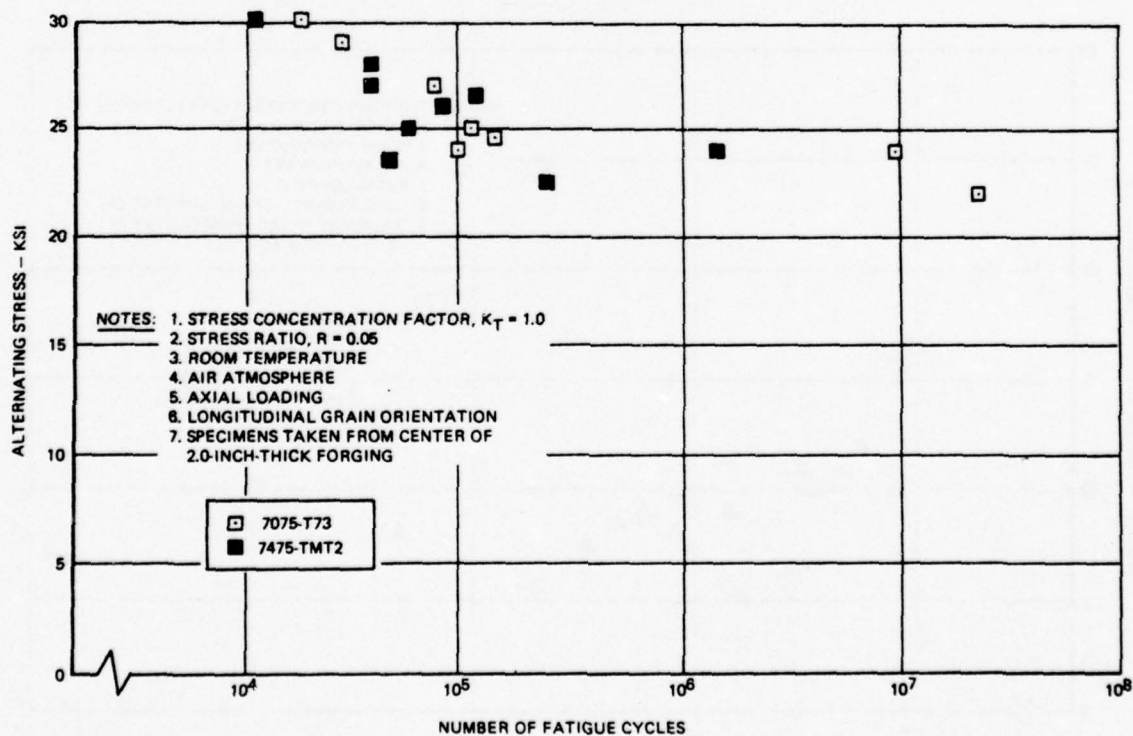


Figure 102. Comparison of Fatigue Strengths for 7075-T73 and 7475-TMT2 Forging, Groups 3 and 20.

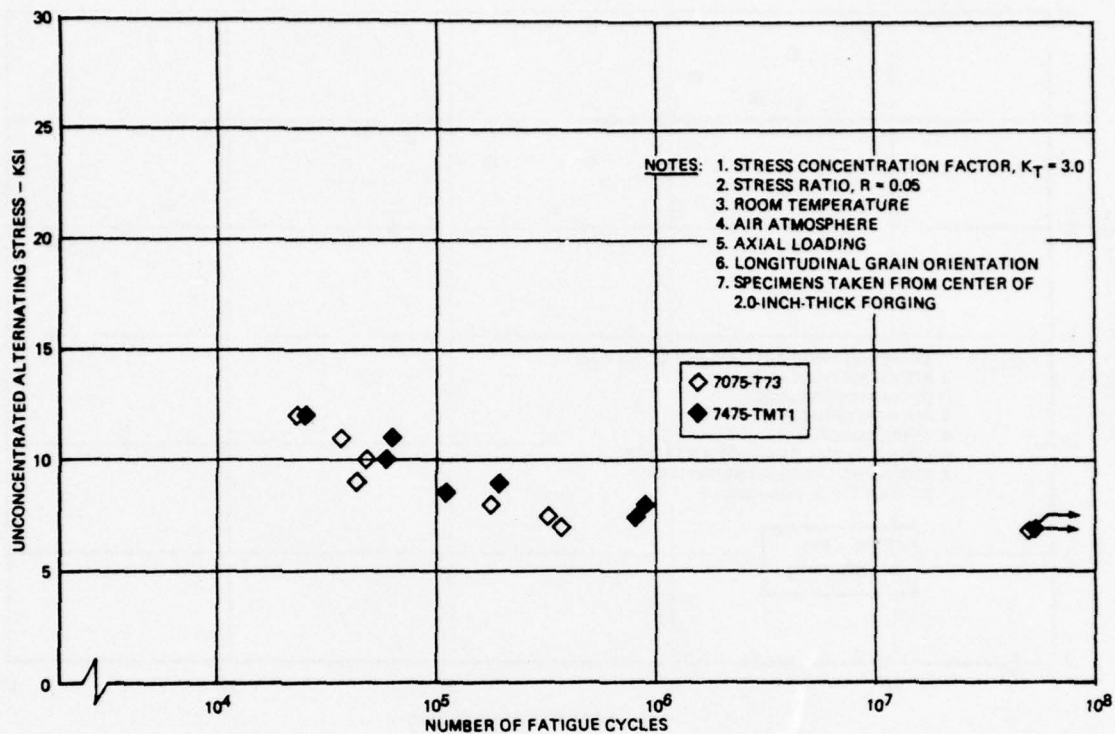


Figure 103. Comparison of Fatigue Strengths for 7075-T73 and 7475-TMT1 Forging, Groups 4 and 13.

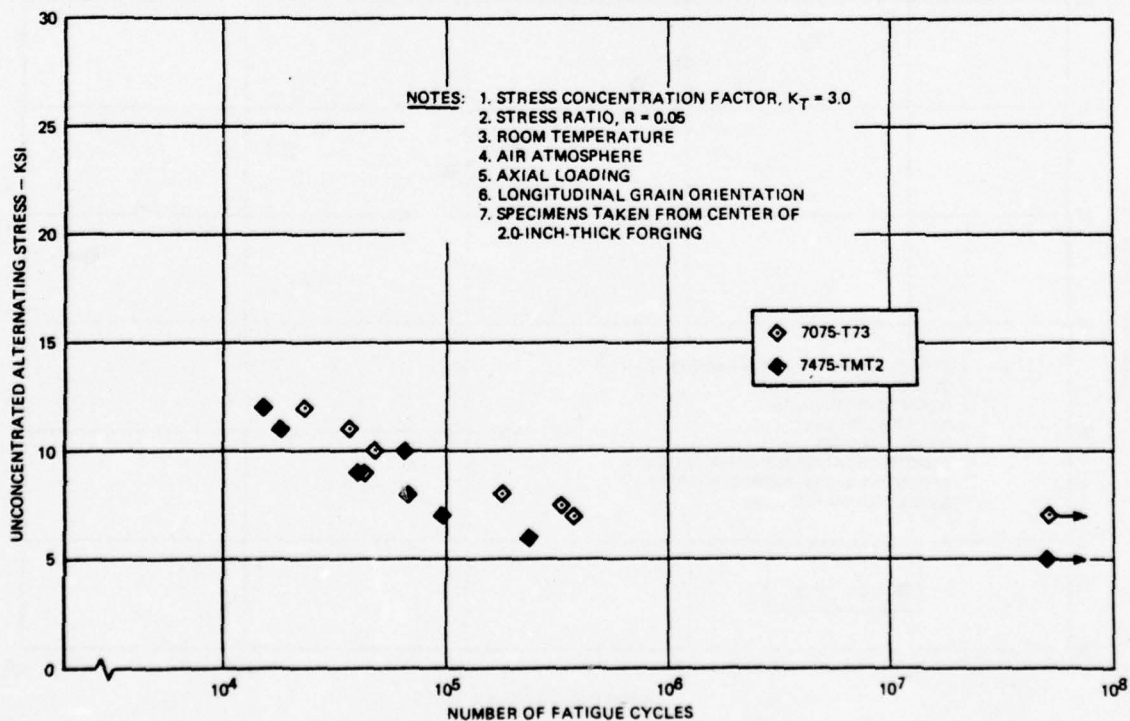


Figure 104. Comparison of Fatigue Strengths for 7075-T73 and 7475-TMT2 Forging, Groups 4 and 23.

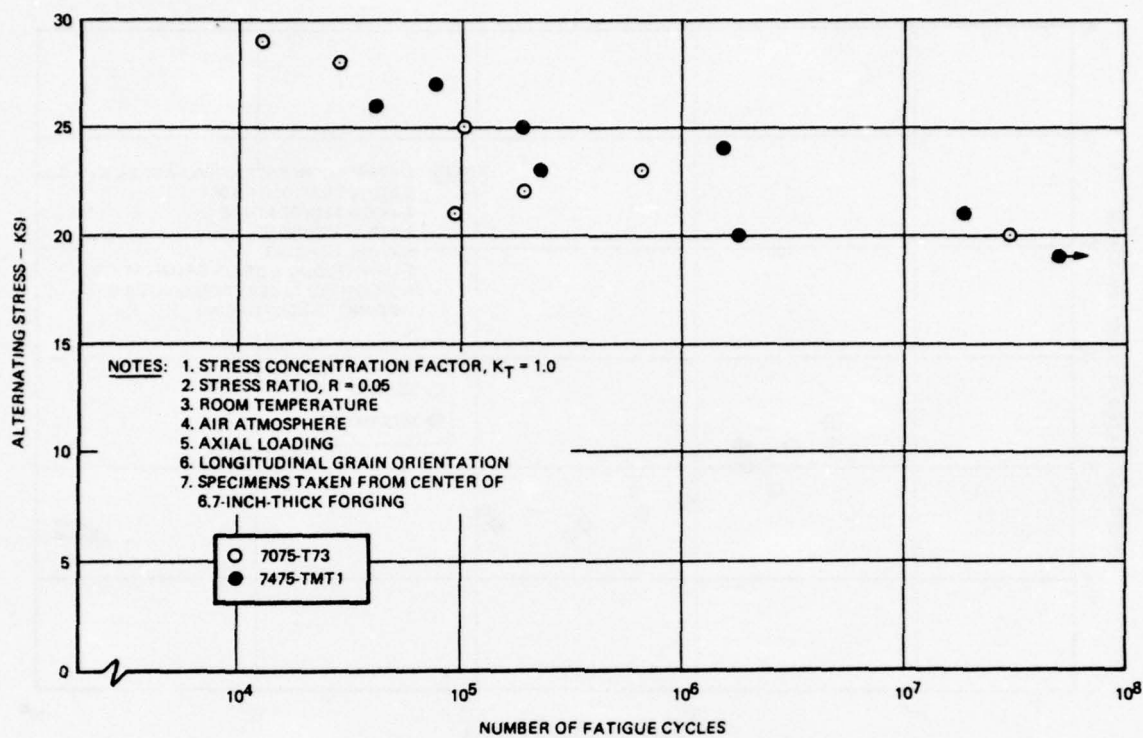


Figure 105. Comparison of Fatigue Strengths for 7075-T73 and 7475-TMT1 Forging, Groups 5 and 15.

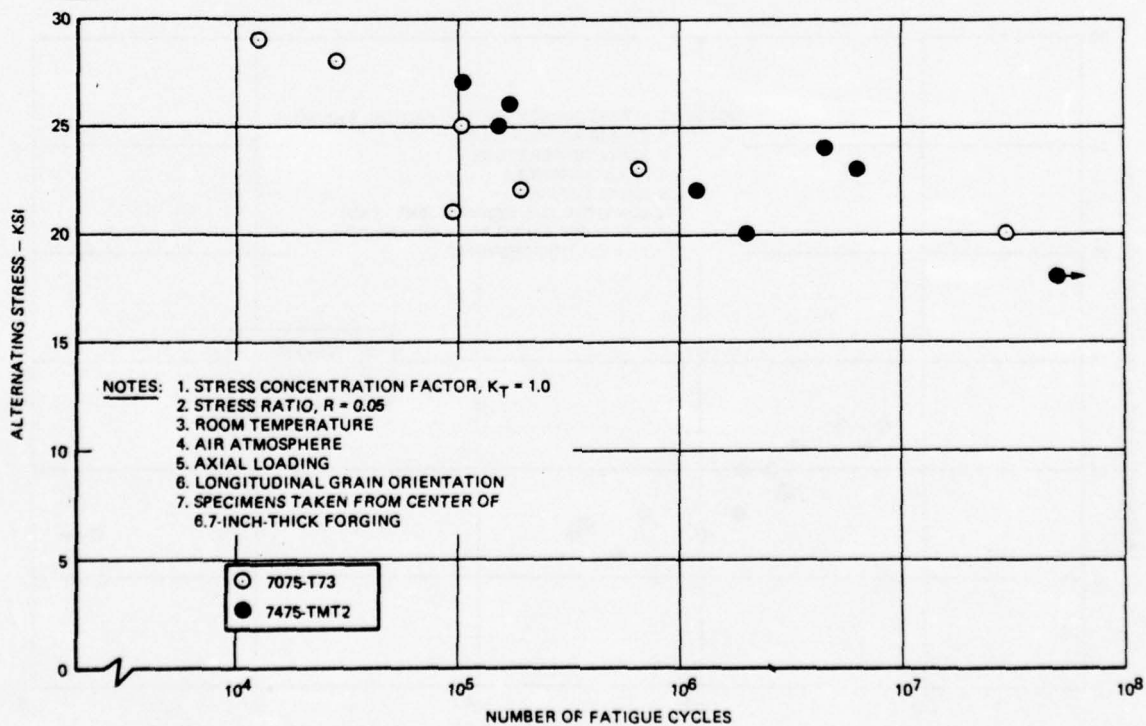


Figure 106. Comparison of Fatigue Strengths for 7075-T73 and 7475-TMT2 Forging, Groups 5 and 25.

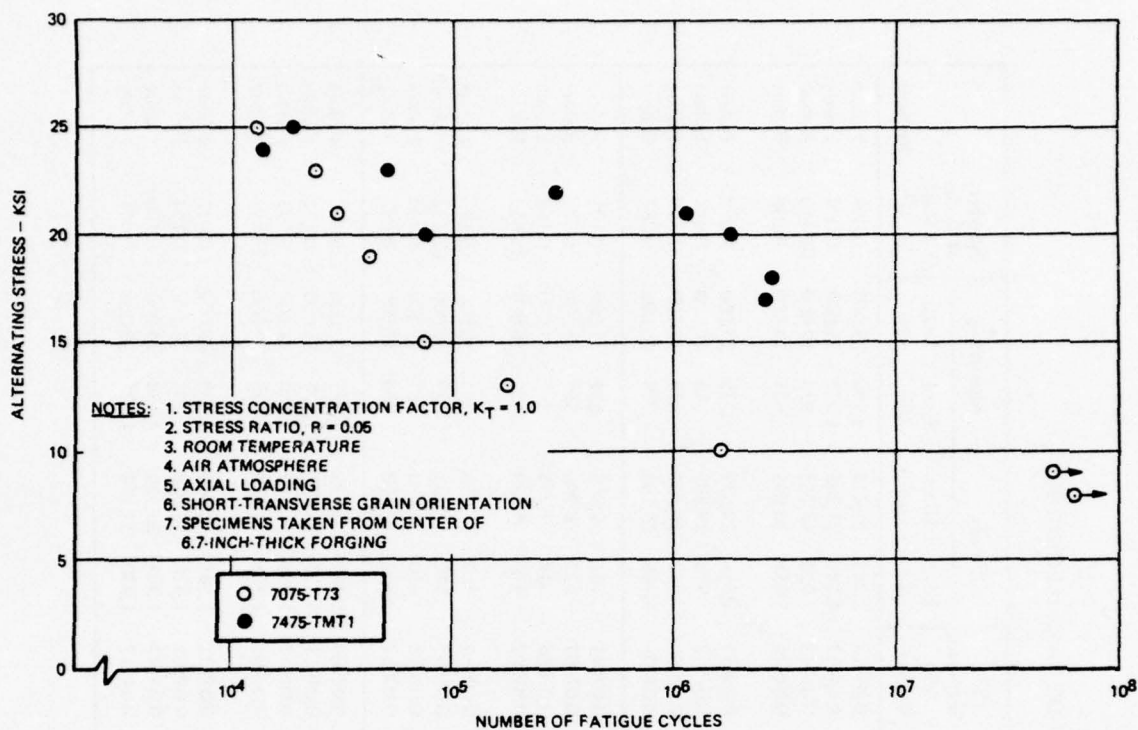


Figure 107. Comparison of Fatigue Strengths for 7075-T73 and 7475-TMT1 Forging, Groups 6 and 16.

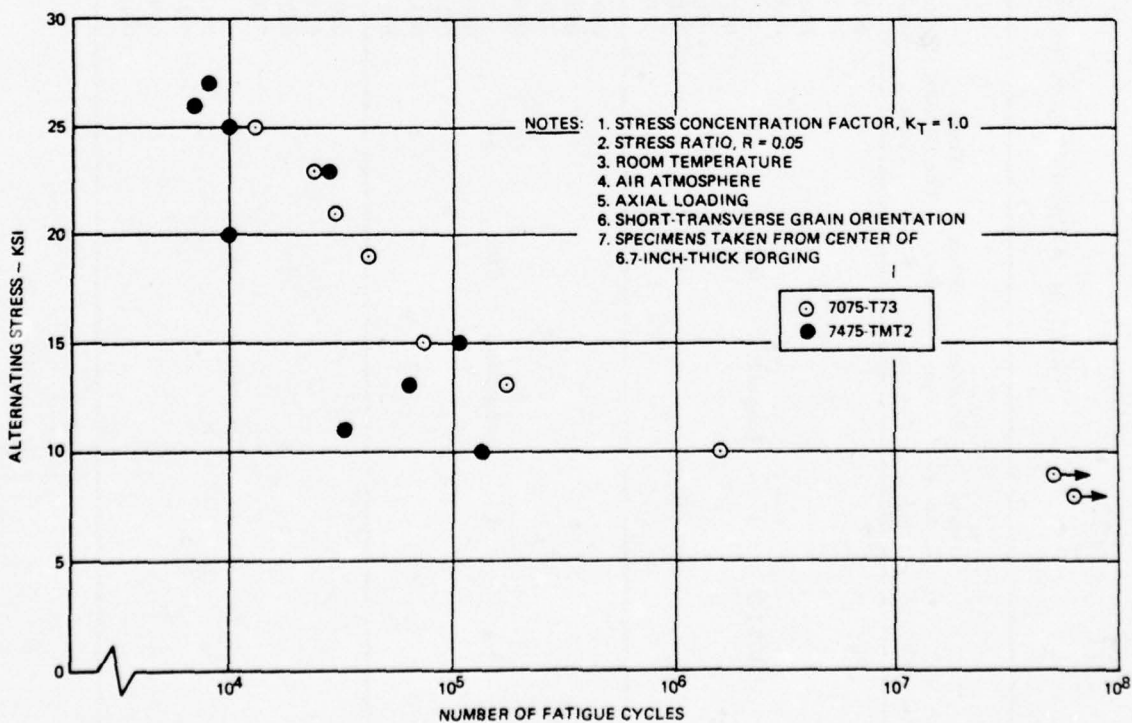


Figure 108. Comparison of Fatigue Strengths for 7075-T73 and 7475-TMT2 Forging, Groups 6 and 26.

TABLE 24. AXIAL-FATIGUE-TEST RESULTS FOR TASK II FORGINGS

Group Number	Material	Forging Thickness (in.)	Specimen Grain Direction	Stress Ratio, R	Stress Concentration Factor	Specimen Number	Cross-Sectional Area (sq in.)	Steady		Alternating		Number of Cycles to Failure, $\times 10^6$	Remarks
								Load (lb)	Stress (psi)	Load (lb)	Stress (psi)		
1	7075-T73	1	Longitudinal	0.05	1.0	0103	30	1,249	25,415	1,130	23,000	0.069	Failure
						0105	30	1,141	23,205	1,032	21,000	0.079	Failure
						0107	30	922	18,785	835	17,000	41.410	Failure
						0109	70	1,033	20,995	935	19,000	0.108	Failure
						0112	70	1,359	27,630	1,229	25,000	0.072	Failure
						0114	70	978	19,890	885	18,000	0.484	Failure
						0116	70	949	19,340	859	17,500	31.520	Failure
						0118	30	1,408	28,730	1,274	26,000	9.061	Failure
2	7075-T73	1	Longitudinal	0.05	3.0	0104	70	701	9,945	634	9,000	0.171	Failure
						0106	30	627	8,840	568	8,000	0.123	Failure
						0108	30	544	7,735	492	7,000	0.108	Failure
						0110	30	470	6,630	426	6,000	13.642	Failure
						0113	30	780	11,050	706	10,000	0.120	Failure
						0115	30	549	7,735	497	7,000	62.132	Runout
						0117	30	430	6,080	389	5,500	0.440	Failure
						0119	30	862	12,160	780	11,000	0.032	Failure
3	7075-T73	2	Longitudinal	0.05	1.0	0203	30	1,465	29,835	1,325	27,000	0.082	Failure
						0205	30	1,357	27,632	1,228	25,000	0.122	Failure
						0207	70	1,304	26,520	1,180	24,000	9.995	Failure
						0209	30	1,191	24,310	1,078	22,000	23.812	Failure
						0212	30	1,581	32,045	1,430	29,000	0.032	Failure
						0214	30	1,328	27,070	1,202	24,500	0.154	Failure
						0216	30	1,304	26,520	1,180	24,000	0.106	Failure
						0218	30	1,630	33,150	1,475	30,000	0.021	Failure

TABLE 24 - Continued

Group Number	Material	Forging Thickness (in.)	Specimen Grain Direction	Stress Ratio, R	Stress Concentration Factor	Specimen Number	Hz	Cross-Sectional Area (sq in.)	Steady		Alternating		Number of Cycles to Failure, $\times 10^6$	Remarks
									Load (lb)	Stress (psi)	Load (lb)	Stress (psi)		
4	7075-T73	2	Longitudinal	0.05	3.0	0204	30	0.07111	786	11,050	711	10,000	0.048	Failure
						0206	30	0.07111	707	9,945	640	9,000	0.043	Failure
						0208	30	0.07078	626	8,840	566	8,000	0.179	Failure
						0210	70	0.07083	548	7,740	496	7,000	51.901	Runout
						0213	30	0.07078	861	12,160	779	11,000	0.037	Failure
						0215	30	0.07106	589	8,290	533	7,500	0.333	Failure
						0217	30	0.07102	942	13,260	852	12,000	0.023	Failure
						0219	30	0.07083	548	7,740	496	7,000	0.375	Failure
5	7075-T73	6.7	Longitudinal	0.05	1.0	0602	30	0.04885	1,080	22,105	977	20,000	30.216	Failure
						0603	30	0.04909	1,519	30,940	1,375	28,000	-	Invalid
						0607	30	0.04924	1,361	27,632	1,231	25,000	0.106	Failure
						0608	70	0.04924	1,252	25,415	1,133	23,000	0.664	Failure
						0610	70	0.04936	1,200	24,310	1,086	22,000	0.196	Failure
						0611	30	0.04905	1,518	30,940	1,373	28,000	0.029	Failure
						0612	30	0.04940	1,583	32,045	1,433	29,000	0.013	Failure
						0613	30	0.04901	1,140	23,210	1,031	21,000	0.096	Failure
6	7075-T73	6.7	Short transverse	0.05	1.0	0301	30	0.04905	1,247	25,415	1,128	23,000	0.024	Failure
						0302	30	0.04917	1,141	23,205	1,032	21,000	0.030	Failure
						0303	70	0.04897	812	16,575	735	15,000	0.075	Failure
						0304	30	0.04921	1,033	20,995	935	19,000	0.042	Failure
						0305	70	0.04909	542	11,050	491	10,000	1.645	Failure
						0306	30	0.04980	715	14,365	647	13,000	0.179	Failure
						0307	70	0.04940	437	8,840	395	8,000	63.639	Runout
						0308	30	0.04936	491	9,945	444	9,000	51.282	Runout
						0309	30	0.04913	1,357	27,630	1,228	25,000	0.013	Failure

TABLE 24 - Continued

Group Number	Material	Forging Thickness (in.)	Specimen Grain Direction	Stress Ratio, R	Stress Concentration Factor	Specimen Number	Hz	Cross-Sectional Area (sq in.)	Steady		Alternating		Number of Cycles to Failure, $\times 10^6$	Remarks
									Load (lb)	Stress (psi)	Load (lb)	Stress (psi)		
7	7475-TMT1	1	Longitudinal	0.05	1.0	0703	30	0.04928	1,525	30,940	1,380	28,000	0.058	Failure
						0705	30	0.04925	1,469	29,840	1,330	27,000	0.124	Failure
						0707	30	0.04917	1,275	25,970	1,154	23,500	0.106	Failure
						0709	30	0.04917	1,413	28,730	1,278	26,000	0.123	Failure
						0712	30	0.04917	1,304	26,520	1,180	24,000	0.612	Failure
						0714	30	0.04925	1,224	24,860	1,108	22,500	0.069	Failure
						0716	70	0.04909	1,085	22,100	982	20,000	0.246	Failure
						0718	70	0.04928	980	19,890	887	18,000	0.532	Failure
8	7475-TMT1	1	Longitudinal	0.05	3.0	0704	30	0.07069	937	13,260	848	12,000	0.015	Failure
						0706	30	0.07054	858	12,160	776	11,000	0.022	Failure
						0708	30	0.07059	780	11,050	706	10,000	0.046	Failure
						0710	30	0.07078	704	9,950	637	9,000	0.066	Failure
						0713	70	0.07069	625	8,840	565	8,000	0.179	Failure
						0715	30	0.07054	545	7,730	494	7,000	14.651	Failure
						0717	30	0.07059	468	6,630	424	6,000	51.577	Runout
						0719	30	0.07045	584	8,290	528	7,500	0.120	Failure
9	7475-TMT1	2	Longitudinal	-1	1.0	0801	30	0.04909	0	0	2,455	50,000	0.015	Failure
						0802	30	0.04913	0	0	1,965	40,000	0.072	Failure
						0803	30	0.04909	0	0	1,718	35,000	0.184	Failure
						0804	30	0.04917	0	0	1,475	30,000	1.117	Failure
						0805	30	0.04901	0	0	2,695	55,000	0.003	Failure
						0806	30	0.04909	0	0	2,602	53,000	0.009	Failure
						0807	70	0.04909	0	0	1,227	25,000	12.343	Failure
						0808	30	0.04909	0	0	1,129	23,000	51.617	Runout

TABLE 24 -- Continued

Group Number	Material	Forging Thickness (in.)	Specimen Grain Direction	Stress Ratio, R	Stress Concentration Factor	Specimen Number	Hz	Cross-Sectional Area (sq in.)	Steady		Alternating		Number of Cycles to Failure, $\times 10^6$	Remarks
									Load (lb)	Stress (psi)	Load (lb)	Stress (psi)		
10	7475-TMT1	2	Longitudinal	0.05	1.0	0818	30	0.04870	1,614	33,150	1,461	30,000	0.022	Failure
						0819	30	0.04917	1,521	30,940	1,377	28,000	0.039	Failure
						0820	30	0.04909	1,410	28,730	1,276	26,000	0.172	Failure
						0821	30	0.04909	1,356	27,630	1,227	25,000	0.231	Failure
						0822	30	0.04909	1,329	27,070	1,203	24,500	0.242	Failure
						0823	30	0.04909	1,302	26,520	1,178	24,000	3.117	Failure
						0824	30	0.04909	1,464	29,840	1,325	27,000	0.173	Failure
						0825	30	0.04909	1,275	25,970	1,154	23,500	1.656	Failure
11	7475-TMT1	2	Longitudinal	0.50	1.0	0809	30	0.04909	2,945	60,000	982	20,000	—	Yielded
						0810	30	0.04909	2,062	42,000	687	14,000	51.745	Runout
						0811	30	0.04901	2,352	48,000	784	16,000	—	Thread Failure
						0812	30	0.04901	2,352	48,000	784	16,000	0.151	Failure
						0813	30	0.04909	2,504	51,000	835	17,000	—	Thread Failure
						0814	30	0.04909	2,504	51,000	835	17,000	0.115	Failure
						0815	30	0.04913	2,653	54,000	884	18,000	—	Yielded
						0816	70	0.04913	2,211	45,000	737	15,000	0.093	Failure
12	7475-TMT1	2	Longitudinal	-1.0	3.0	0817	30	0.04909	2,135	43,500	712	14,500	54.533	Runout
						0845	30	0.07083	0	0	1,771	25,000	0.008	Failure
						0846	30	0.07083	0	0	1,417	20,000	0.015	Failure
						0847	30	0.07073	0	0	1,132	16,000	0.050	Failure
						0848	30	0.07054	0	0	846	12,000	2.015	Failure
						0849	30	0.07054	0	0	988	14,000	0.068	Failure
						0850	30	0.07092	0	0	922	13,000	0.058	Failure
						0851	70	0.07073	0	0	813	11,500	0.358	Failure
						0852	30	0.07102	0	0	710	10,000	32.536	Failure

TABLE 24 - Continued

Group Number	Material	Forging Thickness (in.)	Specimen Grain Direction	Stress Ratio, R	Stress Concentration Factor	Specimen Number	Hz	Cross-Sectional Area (sq in.)	Steady		Alternating		Number of Cycles to Failure, $\times 10^6$	Remarks
									Load (lb)	Stress (psi)	Load (lb)	Stress (psi)		
13	7475-TMTI	2	Longitudinal	0.05	3.0	0826	30	0.07078	939	13,260	849	12,000	0.025	Failure
						0830	30	0.07069	781	11,050	707	10,000	0.059	Failure
						0831	30	0.07078	626	8,840	566	8,000	0.910	Failure
						0832	30	0.07087	862	12,160	780	11,000	0.063	Failure
						0833	30	0.07069	703	9,950	636	9,000	0.192	Failure
						0834	30	0.07092	548	7,730	496	7,000	54.099	Runout
14	7475-TMTI	2	Longitudinal	0.50	3.0	0835	30	0.07063	664	9,390	601	8,500	0.111	Failure
						0836	30	0.07083	587	8,290	531	7,500	0.818	Failure
						0837	30	0.07073	1,062	15,000	354	5,000	54.299	Runout
						0838	30	0.07069	1,272	18,000	424	6,000	0.862	Failure
						0839	30	0.07069	1,484	21,000	495	7,000	0.101	Failure
						0840	30	0.07092	1,596	22,500	532	7,500	0.072	Failure
15	7475-TMTI	6.7	Longitudinal	0.05	1.0	0841	30	0.07059	1,377	19,500	459	6,500	0.126	Failure
						0842	30	0.07078	1,274	18,000	425	6,000	0.291	Failure
						0843	30	0.07092	1,170	16,500	390	5,500	54.459	Runout
						0844	70	0.07054	1,270	18,000	423	6,000	0.121	Failure
						1202	30	0.04928	1,471	20,840	1,331	27,000	0.079	Failure
						1203	30	0.04917	1,413	28,730	1,278	26,000	0.042	Failure
15	7475-TMTI	6.7	Longitudinal	0.05	1.0	1207	30	0.04909	1,356	27,630	1,227	25,000	0.193	Failure
						1208	30	0.04909	1,302	26,520	1,178	24,000	1.566	Failure
						1210	30	0.04925	1,252	25,420	1,133	23,000	0.231	Failure
						1211	30	0.04913	1,140	23,210	1,032	21,000	19.008	Failure
						1212	70	0.04909	1,085	22,100	982	20,000	1.810	Failure
						1213	30	0.04928	1,035	20,995	936	19,000	50.016	Runout

TABLE 24 - Continued

Group Number	Material	Forging Thickness (in.)	Specimen Grain Direction	Stress Ratio, R	Stress Concentration Factor	Specimen Number	Hz	Cross-Sectional Area (sq in.)	Steady		Alternating		Number of Cycles to Failure, $\times 10^6$	Remarks
									Load (lb)	Stress (psi)	Load (lb)	Stress (psi)		
16	7475-TMT1	6.7	Short transverse	0.05	1.0	0901	30	0.04909	1,356	27,630	1,227	25,000	0.019	Failure
						0902	30	0.04913	1,249	25,420	1,130	23,000	0.051	Failure
						0903	30	0.04909	1,139	23,210	1,031	21,000	1.172	Failure
						0904	30	0.04909	1,302	26,520	1,178	24,000	0.014	Failure
						0905	30	0.04909	1,193	24,310	1,080	22,000	0.295	Failure
						0906	30	0.04913	1,086	22,100	983	20,000	0.075	Failure
						0907	30	0.04913	977	19,890	884	18,000	2.821	Failure
						0908	30	0.04909	1,086	22,100	983	20,000	1.819	Failure
						0909	30	0.04909	922	18,790	835	17,000	2.621	Failure
17	7475-TMT2	1	Longitudinal	0.05	1.0	1303	30	0.04909	1,356	27,630	1,227	25,000	0.583	Failure
						1305	30	0.04909	1,248	25,420	1,129	23,000	2.858	Failure
						1307	30	0.04909	1,085	22,100	982	20,000	28.791	Failure
						1309	70	0.04909	1,031	20,995	933	19,000	64.700	Runout
						1312	30	0.04909	1,410	28,730	1,276	26,000	0.110	Failure
						1314	30	0.04909	1,302	26,520	1,178	24,000	0.448	Failure
18	7475-TMT2	1	Longitudinal	0.05	3.0	1316	30	0.04909	1,464	29,840	1,325	27,000	0.100	Failure
						1318	30	0.04909	1,519	30,940	1,375	28,000	0.053	Failure
						1304	30	0.07069	703	9,950	636	9,000	0.070	Failure
						1306	30	0.07069	860	12,160	778	11,000	0.033	Failure
						1308	30	0.07054	779	11,050	705	10,000	0.028	Failure
						1310	30	0.07069	625	8,840	565	8,000	2.183	Failure
						1313	30	0.07045	934	13,260	845	12,000	0.018	Failure
						1315	70	0.07069	546	7,730	495	7,000	62.339	Runout
						1317	30	0.07045	662	9,390	599	8,500	0.226	Failure
						1319	30	0.07069	586	8,290	530	7,500	0.310	Failure

TABLE 24 - Continued

Group Number	Material	Forging Thickness (in.)	Specimen Grain Direction	Stress Ratio, R	Stress Concentration Factor	Specimen Number	Hz	Cross-Sectional Area (sq in.)	Steady		Alternating		Number of Cycles to Failure, $\times 10^6$	Remarks
									Load (lb)	Stress (psi)	Load (lb)	Stress (psi)		
19	7475-TMT2	2	Longitudinal	-1.0	1.0	1401	30	0.04913	0	0	2,456	50,000	0.014	Failure
						1402	30	0.04909	0	0	1,964	40,000	0.066	Failure
						1403	30	0.04913	0	0	1,719	35,000	0.176	Failure
						1404	30	0.04913	0	0	1,474	30,000	1.359	Failure
						1405	30	0.04909	0	0	2,209	45,000	0.023	Failure
						1406	30	0.04909	0	0	1,227	25,000	0.422	Failure
						1407	70	0.04913	0	0	1,032	21,000	1.116	Failure
						1408	30	0.04913	0	0	884	18,000	50.355	Runout
20	7475-TMT2	2	Longitudinal	0.05	1.0	1417	30	0.04913	1,629	33,150	1,474	30,000	0.013	Failure
						1418	30	0.04909	1,519	30,940	1,375	28,000	0.043	Failure
						1419	30	0.04909	1,464	29,840	1,325	27,000	0.043	Failure
						1420	30	0.04909	1,410	28,730	1,276	26,000	0.899	Failure
						1421	30	0.04909	1,356	27,630	1,227	25,000	0.063	Failure
						1422	30	0.04909	1,437	29,280	1,301	26,500	0.128	Failure
						1423	70	0.04909	1,275	25,970	1,154	23,500	0.052	Failure
						1424	30	0.04909	1,302	26,520	1,178	24,000	1.560	Failure
21	7475-TMT2	2	Longitudinal	0.50	1.0	1425	70	0.04909	1,224	24,860	1,108	22,500	0.265	Failure
						1409	30	0.04913	2,542	51,750	847	17,250	0.075	Failure
						1410	30	0.04909	2,284	46,500	761	15,500	27.257	Failure
						1411	30	0.04897	2,350	48,000	784	16,000	0.111	Failure
						1412	30	0.04909	2,430	49,500	810	16,500	0.058	Failure
						1413	30	0.04909	2,209	45,000	736	15,000	31.422	Failure
						1414	30	0.04913	2,137	43,500	712	14,500	54.697	Runout
						1415	30	0.04913	2,469	50,250	823	16,750	0.124	Failure
						1416	30	0.04917	2,507	51,000	836	17,000	0.080	Failure

TABLE 24 - Continued

Group Number	Material	Forging Thickness (in.)	Specimen Grain Direction	Stress Ratio, R	Stress Concentration Factor	Specimen Number	Hz	Cross-Sectional Area (sq in.)	Steady		Alternating		Number of Cycles to Failure, X 10 ⁶	Remarks
									Load (lb)	Stress (psi)	Load (lb)	Stress (psi)		
22	7475-TMT2	2	Longitudinal	-1.0	3.0	1445	30	0.07073	0	0	1,415	20,000	0.012	Failure
						1446	30	0.07073	0	0	1,132	16,000	0.034	Failure
						1447	30	0.07078	0	0	991	14,000	0.033	Failure
						1448	30	0.07087	0	0	850	12,000	0.052	Failure
						1449	30	0.07083	0	0	708	10,000	0.083	Failure
						1450	30	0.07069	0	0	565	8,000	51.235	Runout
						1451	30	0.07087	0	0	634	9,000	0.083	Failure
						1452	30	0.07069	0	0	601	8,500	0.617	Failure
23	7475-TMT2	2	Longitudinal	0.05	3.0	1426	30	0.07069	937	13,260	848	12,000	0.015	Failure
						1430	30	0.07078	861	12,160	779	11,000	0.018	Failure
						1431	30	0.07078	782	11,050	708	10,000	0.066	Failure
						1432	30	0.07078	704	9,950	637	9,000	0.040	Failure
						1433	30	0.07069	625	8,840	565	8,000	0.068	Failure
						1434	30	0.07087	548	7,730	496	7,000	0.096	Failure
						1435	30	0.07069	469	6,630	424	6,000	0.235	Failure
						1436	30	0.07069	391	5,530	353	5,000	50.528	Runout
24	7475-TMT2	2	Longitudinal	0.50	3.0	1437	30	0.07069	1,272	18,000	424	6,000	0.111	Failure
						1438	30	0.07069	1,378	19,500	459	6,500	0.071	Failure
						1439	70	0.07069	1,166	16,500	389	5,500	0.288	Failure
						1440	30	0.07069	1,062	15,000	354	5,000	0.283	Failure
						1441	70	0.07083	956	13,500	319	4,500	0.263	Failure
						1442	70	0.07050	846	12,000	282	4,000	50.000	Runout
						1443	70	0.07083	956	13,500	319	4,500	2.934	Failure
						1444	30	0.07073	1,485	21,000	495	7,000	0.058	Failure

TABLE 24 - Continued

Group Number	Material	Forging Thickness (in.)	Specimen Grain Direction	Stress Ratio, R	Stress Concentration Factor	Specimen Number	Hz	Cross-Sectional Area (sq in.)	Steady		Alternating		Number of Cycles to Failure, $\times 10^6$	Remarks
									Load (lb)	Stress (psi)	Load (lb)	Stress (psi)		
25	7475-TMT2	6.7	Longitudinal	0.05	1.0	1802	30	0.04925	1,469	29,840	1,330	27,000	0.108	Failure
						1803	30	0.04917	1,413	28,730	1,278	26,000	0.174	Failure
						1807	30	0.04913	1,357	27,630	1,228	25,000	0.157	Failure
						1808	30	0.04928	1,307	26,520	1,183	24,000	4.648	Failure
						1810	30	0.04913	1,249	25,420	1,130	23,000	6.434	Failure
						1811	30	0.04917	1,195	24,310	1,082	22,000	1.215	Failure
						1812	30	0.04924	1,088	22,100	985	20,000	2.083	Failure
						1813	30	0.04925	979	19,890	886	18,000	50.327	Runout
26	7475-TMT2	6.7	Short transverse	0.05	1.0	1501	30	0.04909	1,464	29,840	1,325	27,000	0.008	Failure
						1502	30	0.04913	1,357	27,630	1,228	25,000	0.010	Failure
						1503	30	0.04909	1,410	28,730	1,276	26,000	0.007	Failure
						1504	30	0.04909	814	16,580	736	15,000	0.109	Failure
						1505	30	0.04913	1,249	25,420	1,130	23,000	0.028	Failure
						1506	30	0.04913	1,086	22,100	985	20,000	0.010	Failure
						1507	30	0.04913	706	14,370	639	13,000	0.065	Failure
						1508	30	0.04909	597	12,160	540	11,000	0.033	Failure
						1509	30	0.04913	543	11,050	484	10,000	0.139	Failure

TABLE 25. FATIGUE PERFORMANCE OF TASK II FORGINGS
COMPARED TO 7075-T73 AT 50×10^6 CYCLES

Stress Ratio, R	Stress Concentration Factor, K_T	Material							
		7475-TMT1 Thickness (in.)				7475-TMT2 Thickness (in.)			
		1	2	6.7		1	2	6.7	
				L	S-T			L	S-T
-1.0	1.0	-	1.03 ¹	-	-	-	1.00 ¹	-	-
	3.0	-	1.43 ²	-	-	-	1.14 ²	-	-
+0.05	1.0	1.26	1.00	1.01	1.73	1.16	1.00	1.06	0.80
	3.0	1.15	0.93	-	-	1.23	0.67	-	-
+0.50	1.0	-	1.17 ³	-	-	-	1.20 ³	-	-
	3.0	-	1.25 ⁴	-	-	-	1.06 ⁴	-	-

NOTES: 1. Estimated 7075-T73 mean endurance limit $\pm 23,000$ psi
2. Estimated 7075-T73 mean endurance limit $\pm 7,000$ psi
3. Estimated 7075-T73 mean endurance limit $\pm 12,500$ psi
4. Estimated 7075-T73 mean endurance limit $\pm 12,500/3 = \pm 4,170$ psi

Source of data on 7075-T73: Mehr, P.L., Spuhler, E.H., and Mayer, L.W., ALCOA ALLOY 7075-T73, Alcoa Green Letter, Revised June 1969 by R. A. Schultz, Aluminum Company of America, Application Engineering Division, Alcoa Center, PA.

TABLE 26. TYPICAL ROCKWELL-HARDNESS VALUES FOR SELECTED FATIGUE SPECIMENS

Specimen Number	TMT	Original Material Thickness (in.)	Grain Orientation	Rockwell Hardness, R_B
0716	1	1	30° from longitudinal	85.5
0906	1	6.7	Short transverse	84.0
1212	1	6.7	Longitudinal	83.5
1303	2	1	Longitudinal	84.0
1437	2	2	Longitudinal	80.0
1447	2	2	Longitudinal	80.0
1508	2	6.7	Short transverse	86.0
1807	2	6.7	Longitudinal	84.5

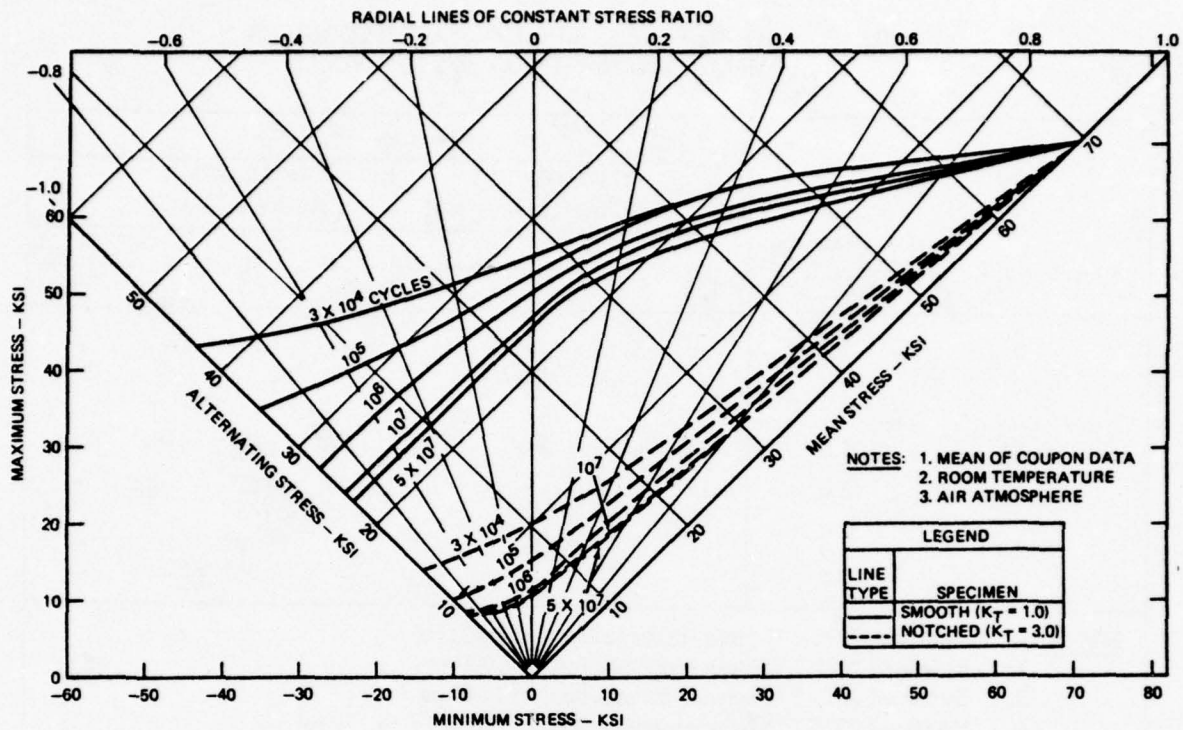


Figure 109. Goodman Diagram for 2-Inch-Thick Forging of 7475-TMT2 Aluminum Alloy.

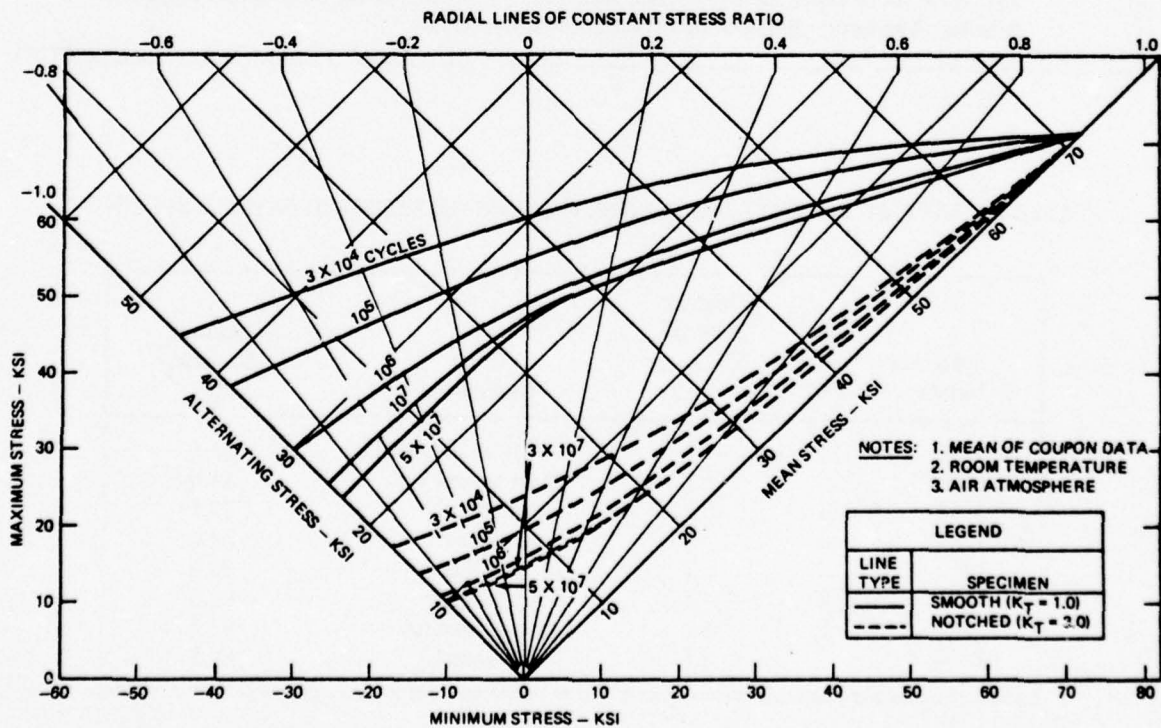
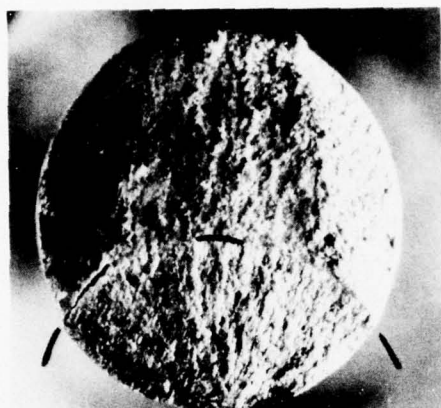
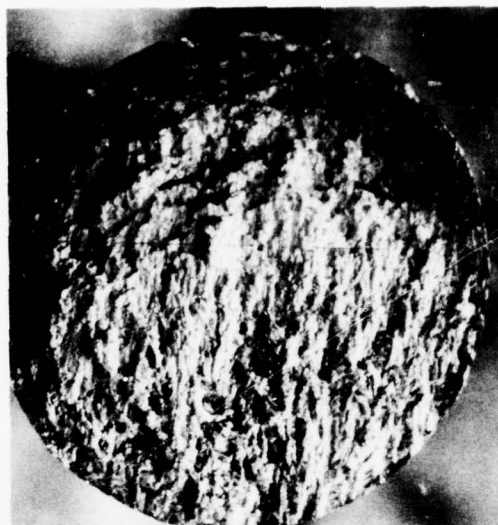


Figure 110. Goodman Diagram for 2-Inch-Thick Forging of 7475-TMT1 Aluminum Alloy.



SPECIMEN 0716

11X



SPECIMEN 0906

11X



SPECIMEN 1212

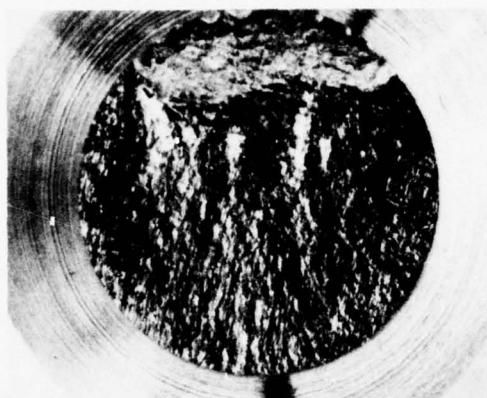
11X



SPECIMEN 1303

11X

Figure 111. Fatigue-Fracture Surface and Origin of Failure for Specimens 0716, 0906, 1212, and 1303.



SPECIMEN 1437

8.5X



SPECIMEN 1447

8.5X



SPECIMEN 1508

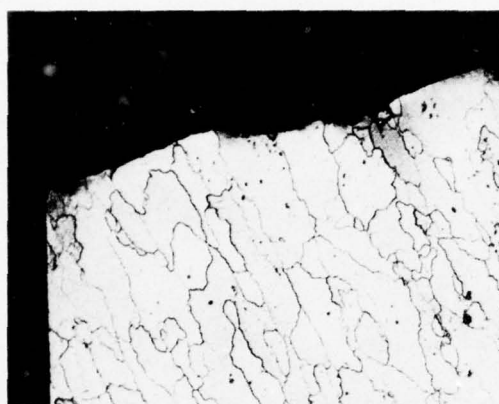
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SPECIMEN 1807

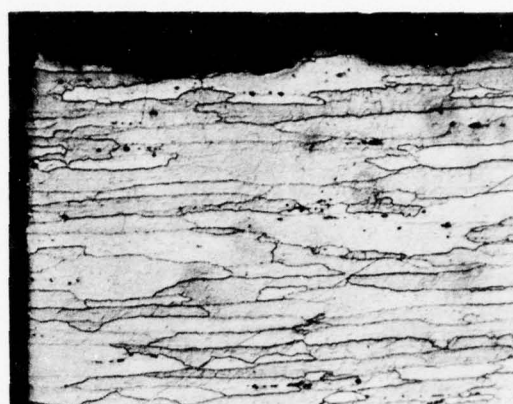
11X

Figure 112. Fatigue-Fracture Surface and Origin of Failure for Specimens 1437, 1447, 1508, and 1807.



SPECIMEN 0716

100X



SPECIMEN 0906

100X



SPECIMEN 1212

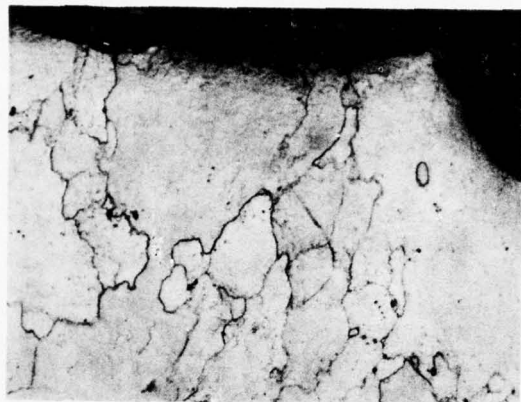
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SPECIMEN 1303

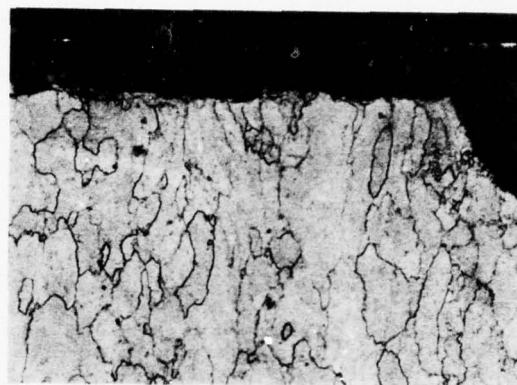
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Figure 113. Grain Orientation and Grain Size for Specimens 0716, 0906, 1212, and 1303.



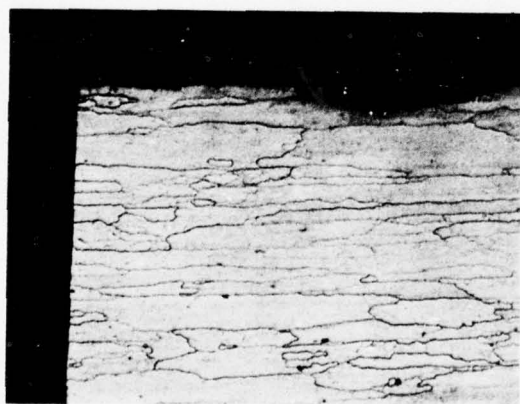
SPECIMEN 1437

100X



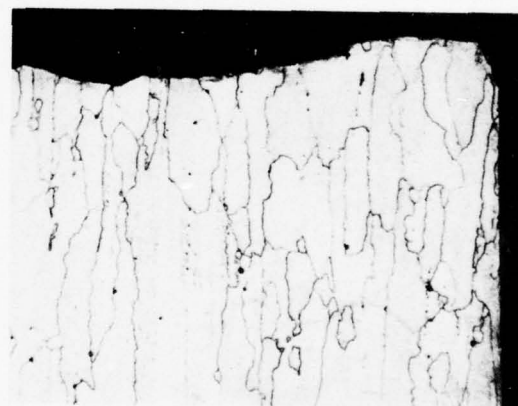
SPECIMEN 1447

100X



SPECIMEN 1508

100X



SPECIMEN 1807

100X

Figure 114. Grain Orientation and Grain Size for Specimens 1437, 1447, 1508, and 1807.

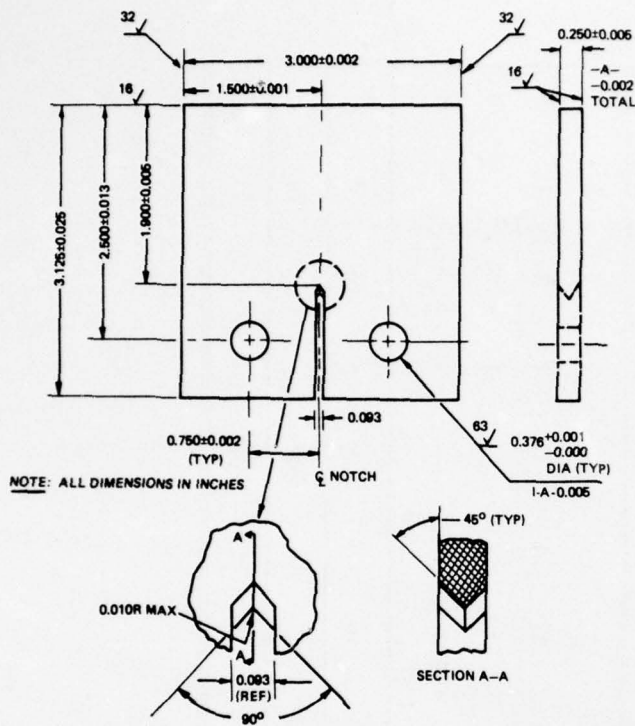


Figure 115. Configuration of Specimen for Fatigue-Crack-Rate Test.

Figure 116. Typical Fatigue-Crack-Propagation Test Setup.

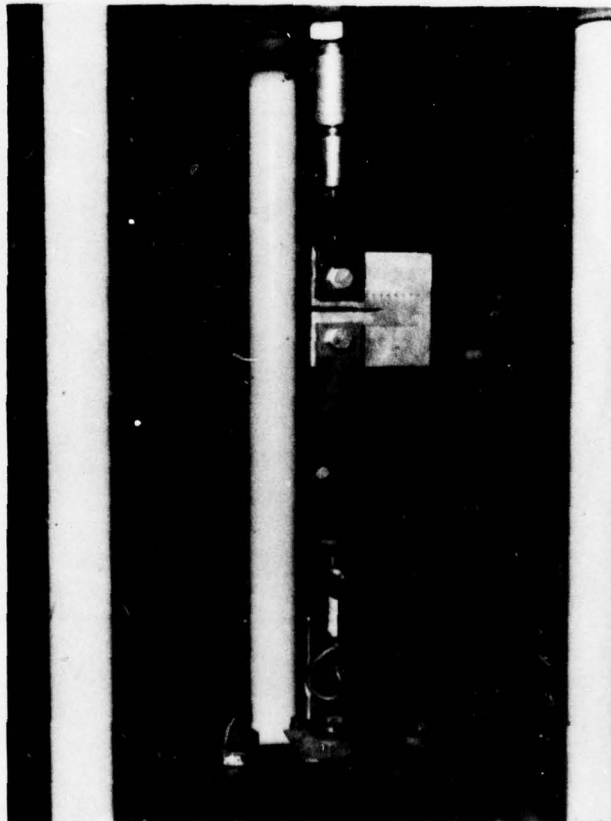


TABLE 27. FATIGUE-CRACK-PROPAGATION-RATE TEST MATRIX

Test Parameters		Number of Specimens								
Stress Ratio, $R = +0.05$		Conventional Process 7075-T73			Advanced Thermal/Mechanical Treatment 7475-TMT1			Advanced Thermal/Mechanical Treatment 7475-TMT2		
Group Number	Specimen Grain Direction Test Environment	Forging Thickness (in.)			Forging Thickness (in.)			Forging Thickness (in.)		
		1.0	2.0	6.7	1.0	2.0	6.7	1.0	2.0	6.7
1	Longitudinal Air, 70°F	2	2	1	2	2	1	2	2	1
2	Longitudinal 3.5% NaCl, 70°F	1	1	1	1	1	1	1	1	1
3	Short transverse Air, 70°F	-	-	1	-	-	1	-	-	1
4	Short transverse 3.5% NaCl, 70°F	-	-	1	-	-	1	-	-	1
Subtotal		3	3	4	3	3	4	3	3	4
Subtotal		10			10			10		
Total		30			30			30		

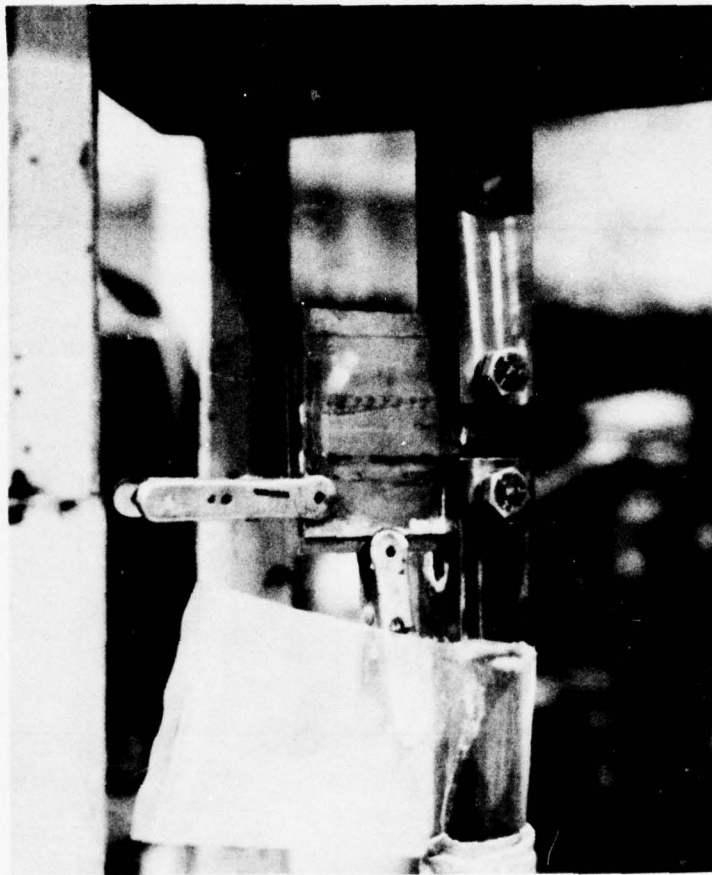


Figure 117. Fatigue-Crack-Propagation Test Setup With Specimen in 3.5-Percent Salt Solution.

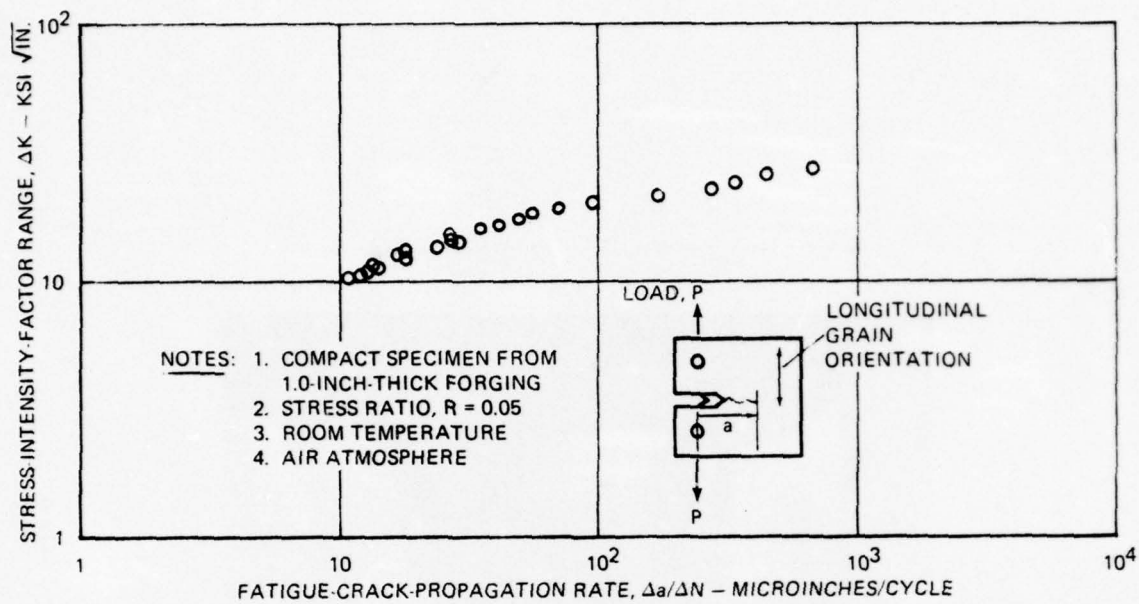


Figure 118. Fatigue-Crack Growth-Rate Performance of Task II Forging, Conventional 7075-T73 Aluminum Alloy, Specimen 0120.

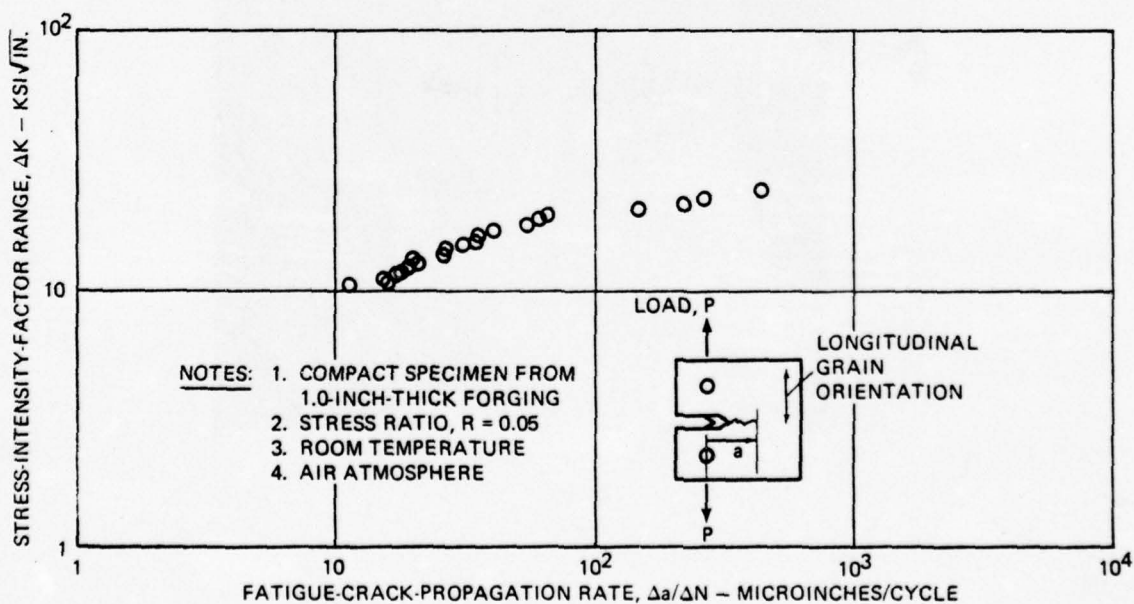


Figure 119. Fatigue-Crack Growth-Rate Performance of Task II Forging, Conventional 7075-T73 Aluminum Alloy, Specimen 0121.

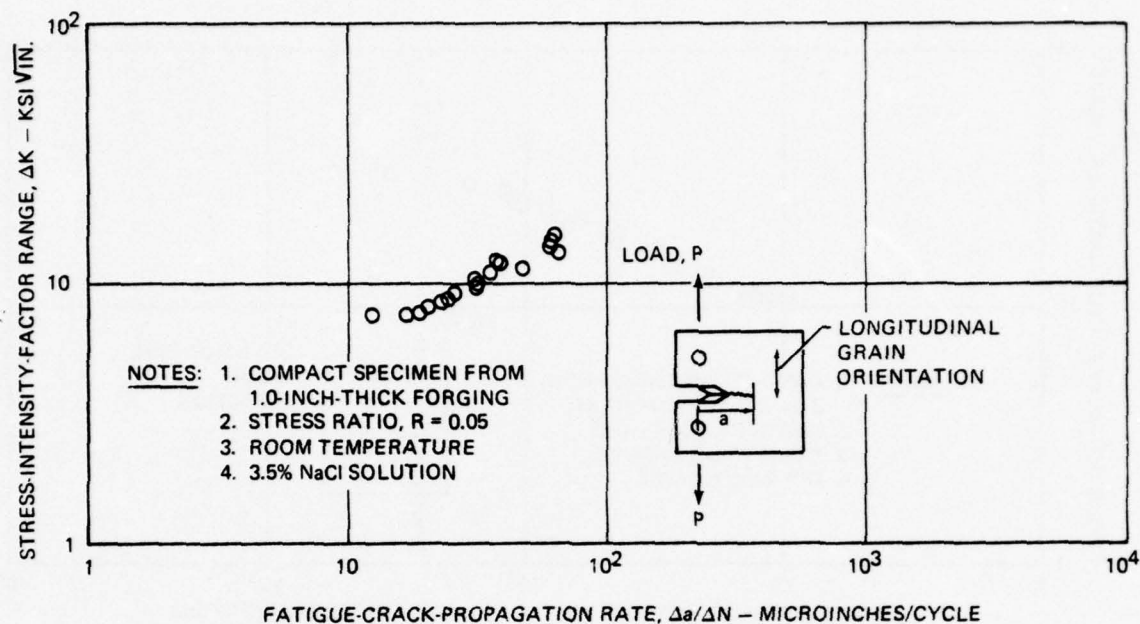


Figure 120. Fatigue-Crack Growth-Rate Performance of Task II Forging, Conventional 7075-T73 Aluminum Alloy, Specimen 0122.

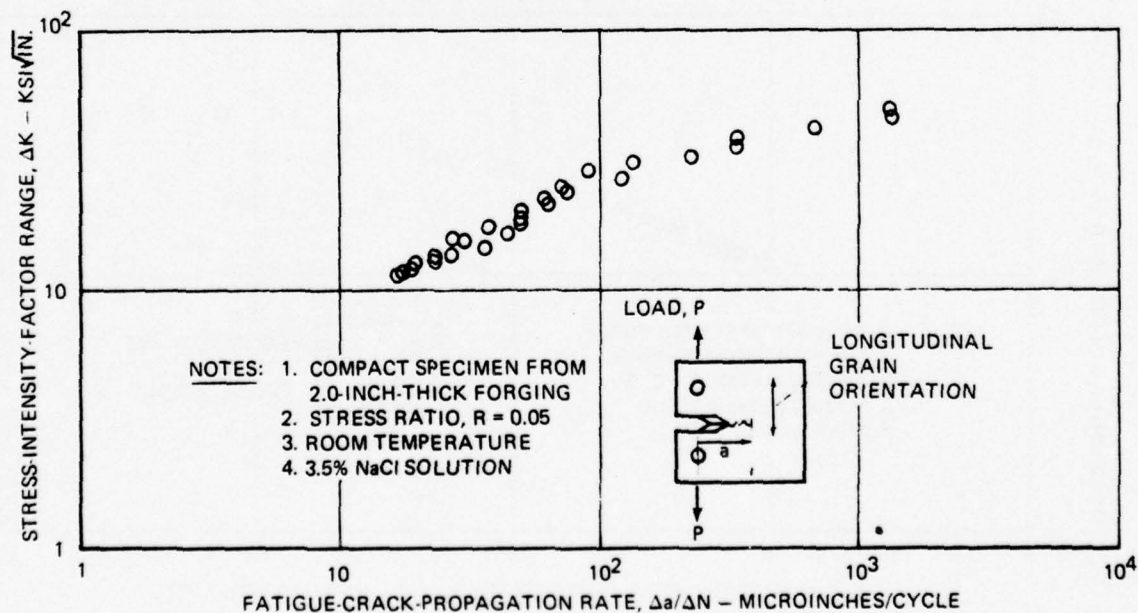


Figure 121. Fatigue-Crack Growth-Rate Performance of Task II Forging, Conventional 7075-T73 Aluminum Alloy, Specimen 0220.

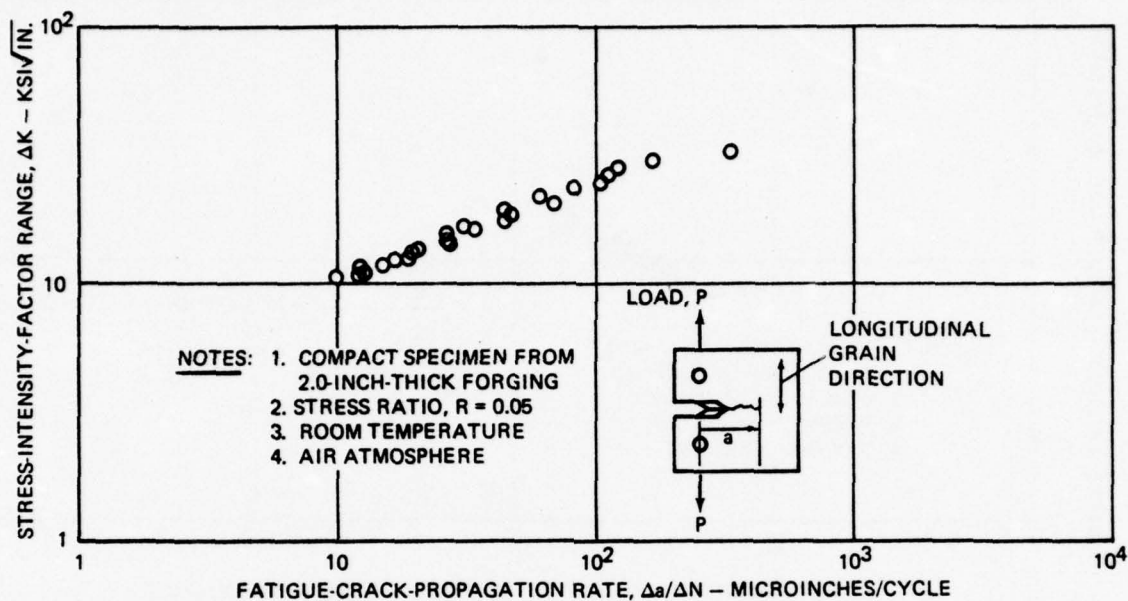


Figure 122. Fatigue-Crack Growth-Rate Performance of Task II Forging, Conventional 7075-T73 Aluminum Alloy, Specimen 0221.

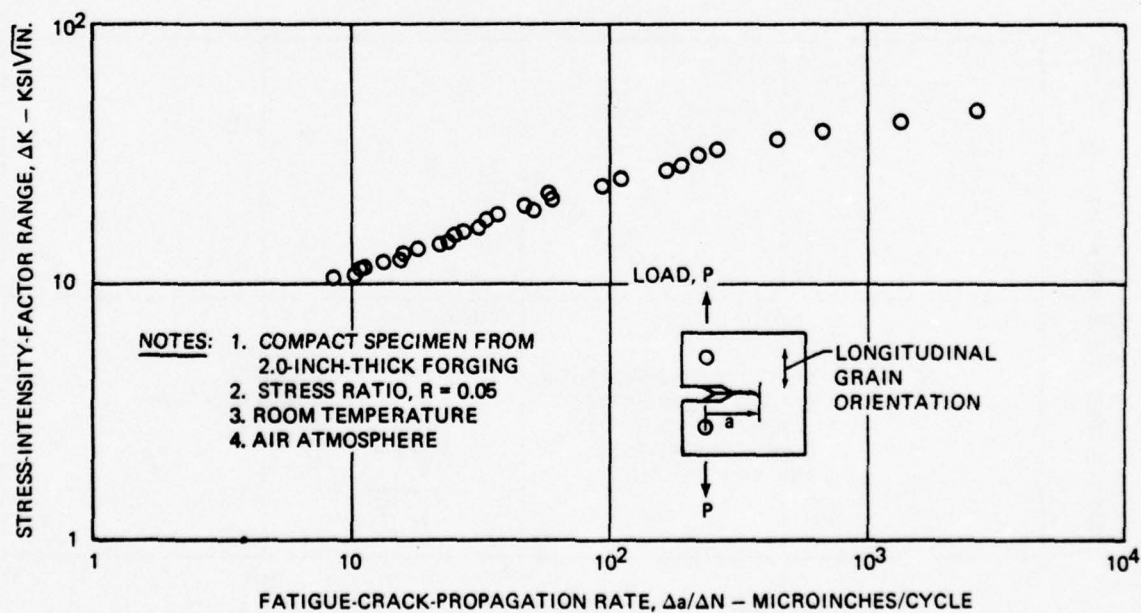


Figure 123. Fatigue-Crack Growth-Rate Performance of Task II Forging, Conventional 7075-T73 Aluminum Alloy, Specimen 0222.

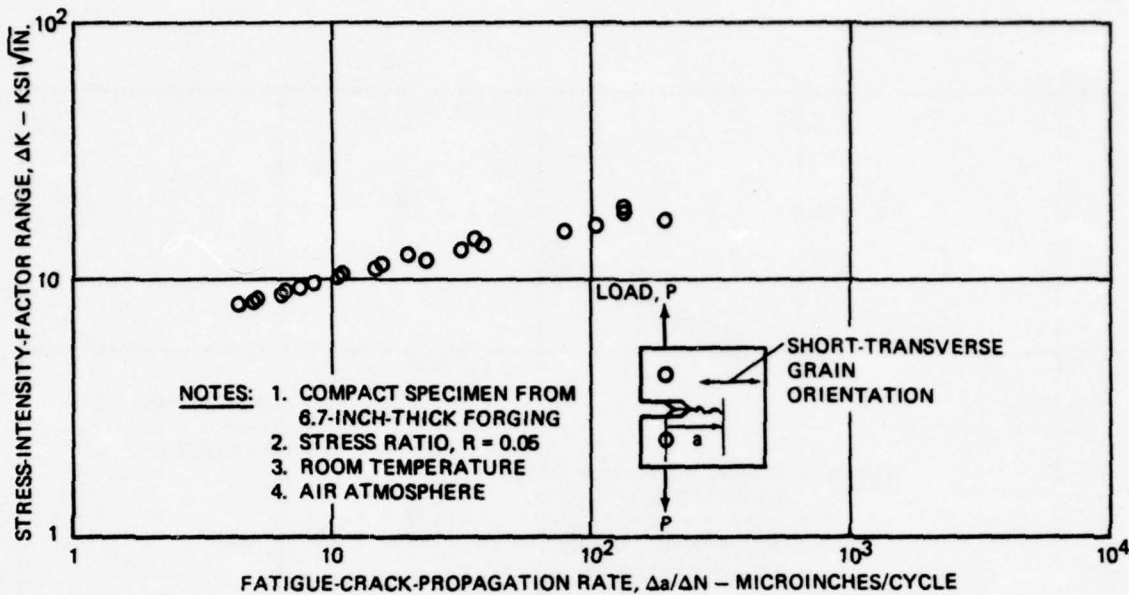


Figure 124. Fatigue-Crack Growth-Rate Performance of Task II Forging, Conventional 7075-T73 Aluminum Alloy, Specimen 0501.

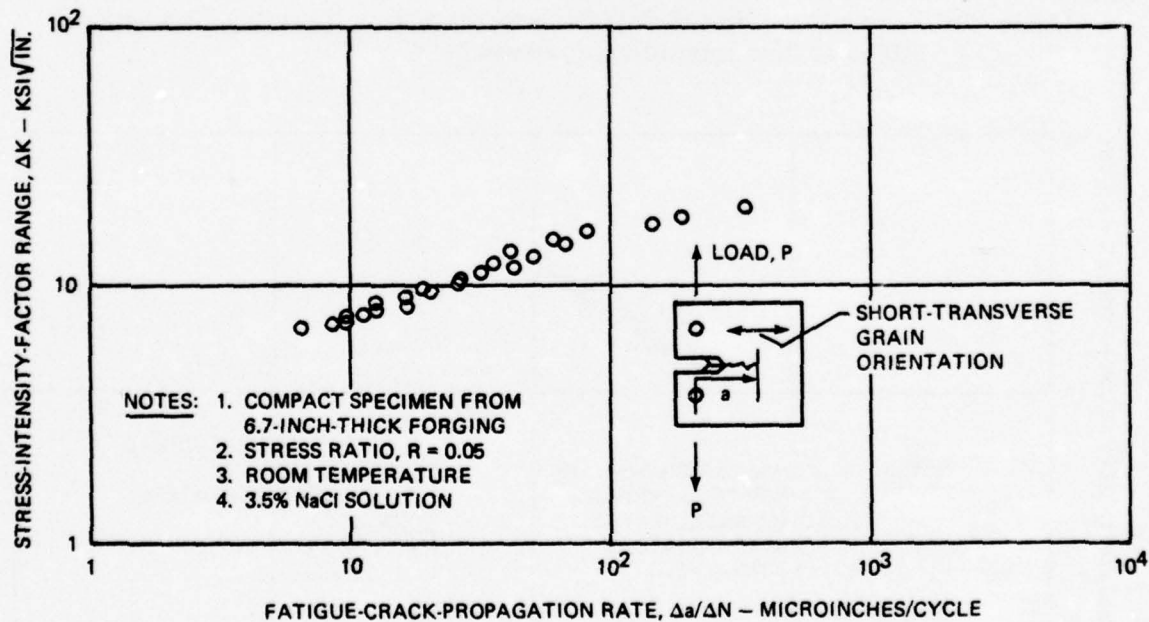


Figure 125. Fatigue-Crack Growth-Rate Performance of Task II Forging, Conventional 7075-T73 Aluminum Alloy, Specimen 0502.

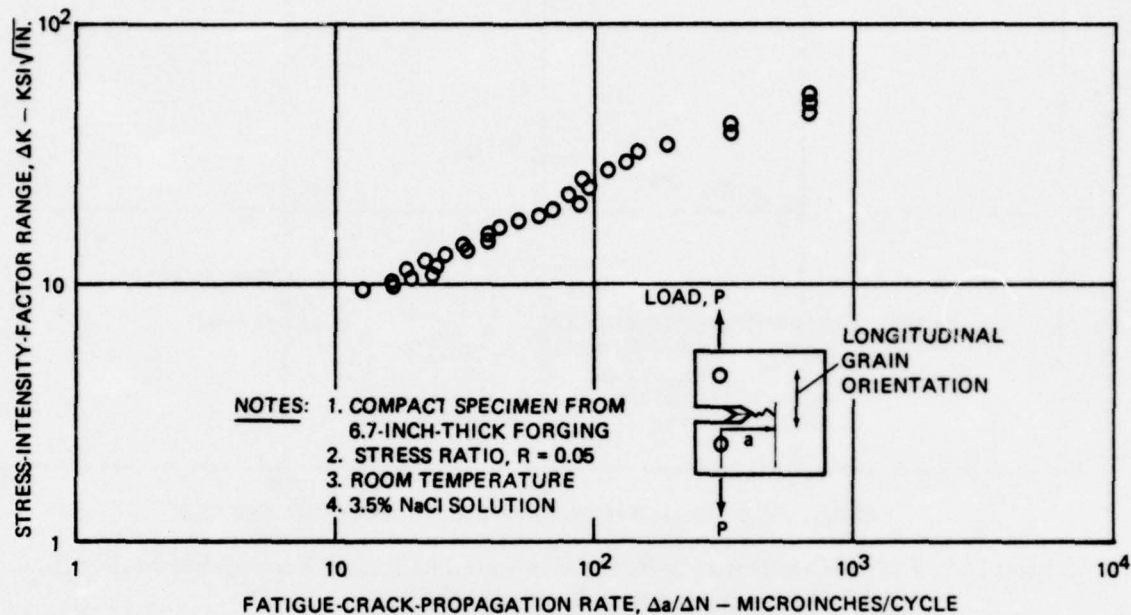


Figure 126. Fatigue-Crack Growth-Rate Performance of Task II Forging, Conventional 7075-T73 Aluminum Alloy, Specimen 0604.

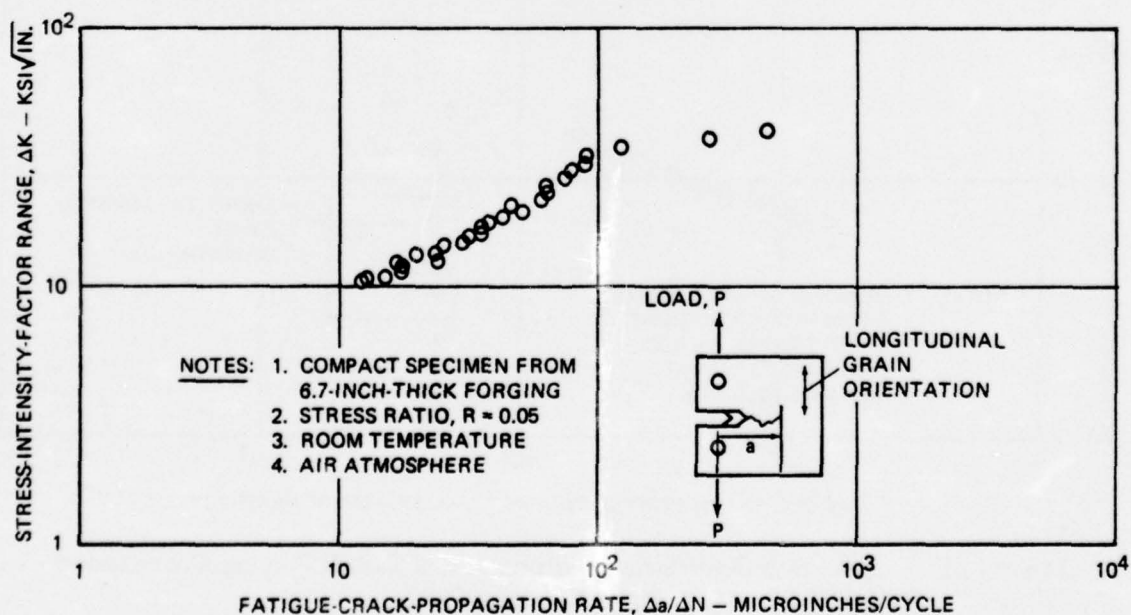


Figure 127. Fatigue-Crack Growth-Rate Performance of Task II Forging, Conventional 7075-T73 Aluminum Alloy, Specimen 0605.

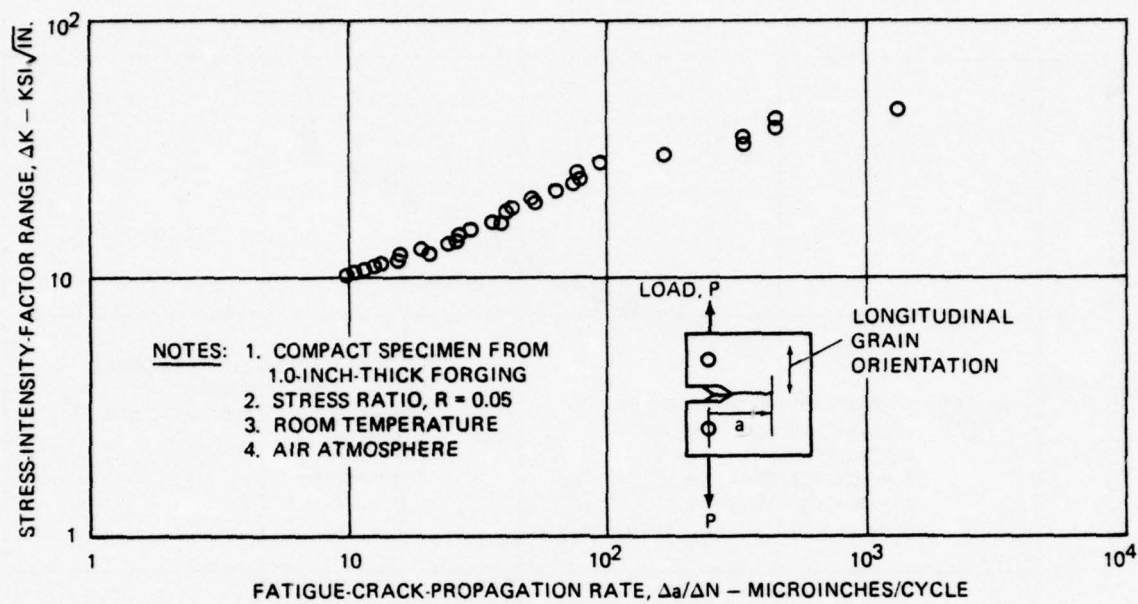


Figure 128. Fatigue-Crack Growth-Rate Performance of Task II Forging, 7475-TMT1 Aluminum Alloy, Specimen 0720.

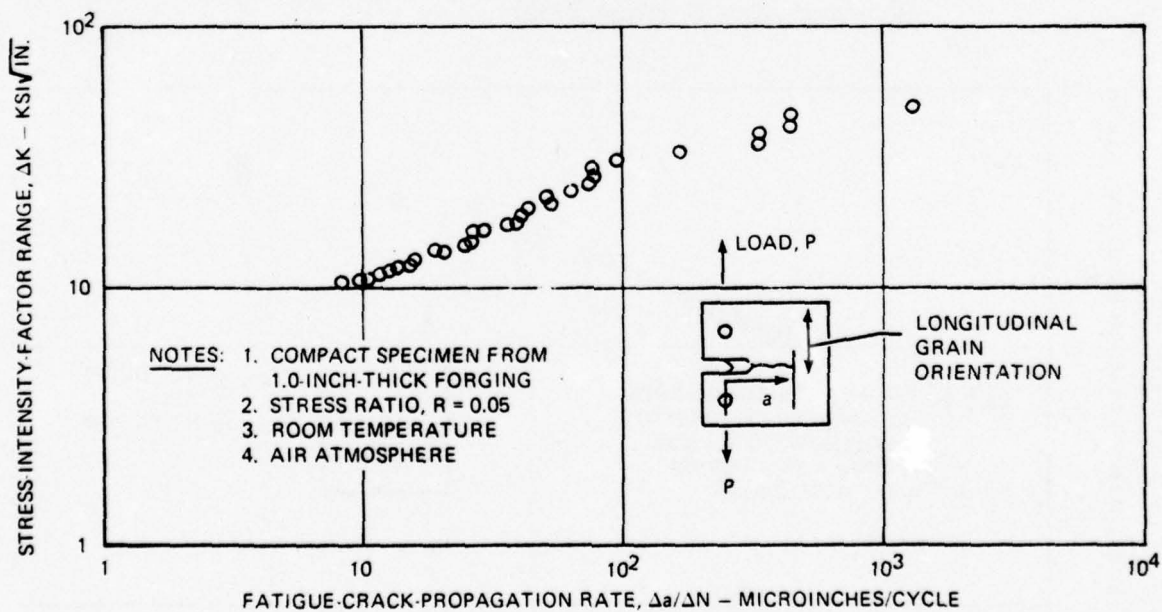


Figure 129. Fatigue-Crack Growth-Rate Performance of Task II Forging, 7475-TMT1 Aluminum Alloy, Specimen 0721.

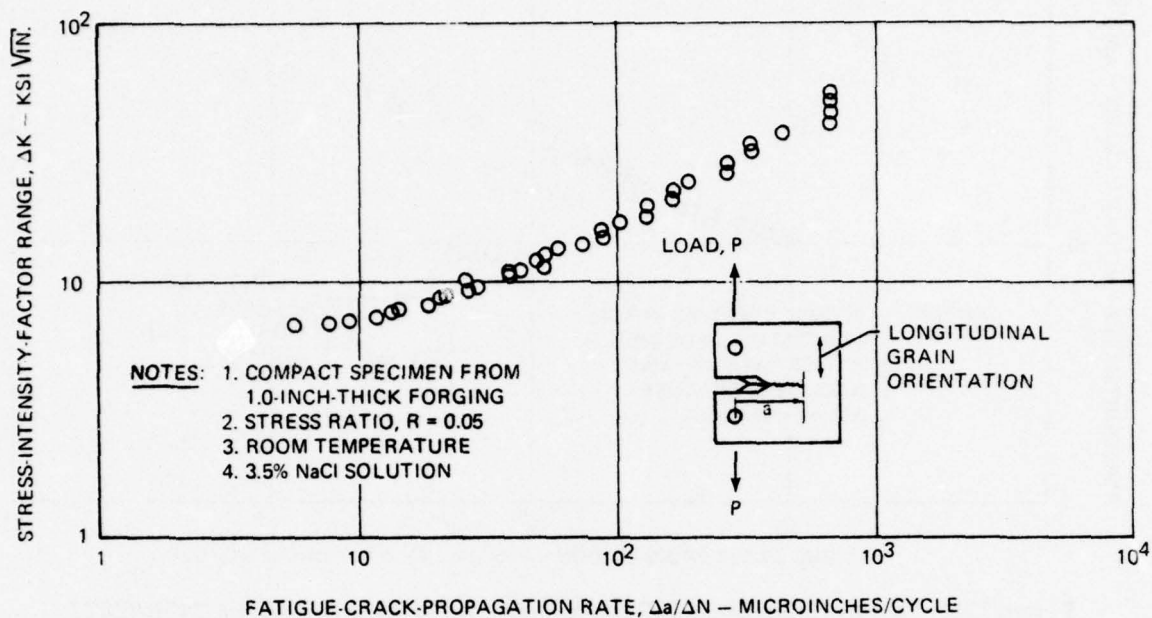


Figure 130. Fatigue-Crack Growth-Rate Performance of Task II Forging, 7475-TMT1 Aluminum Alloy, Specimen 0722.

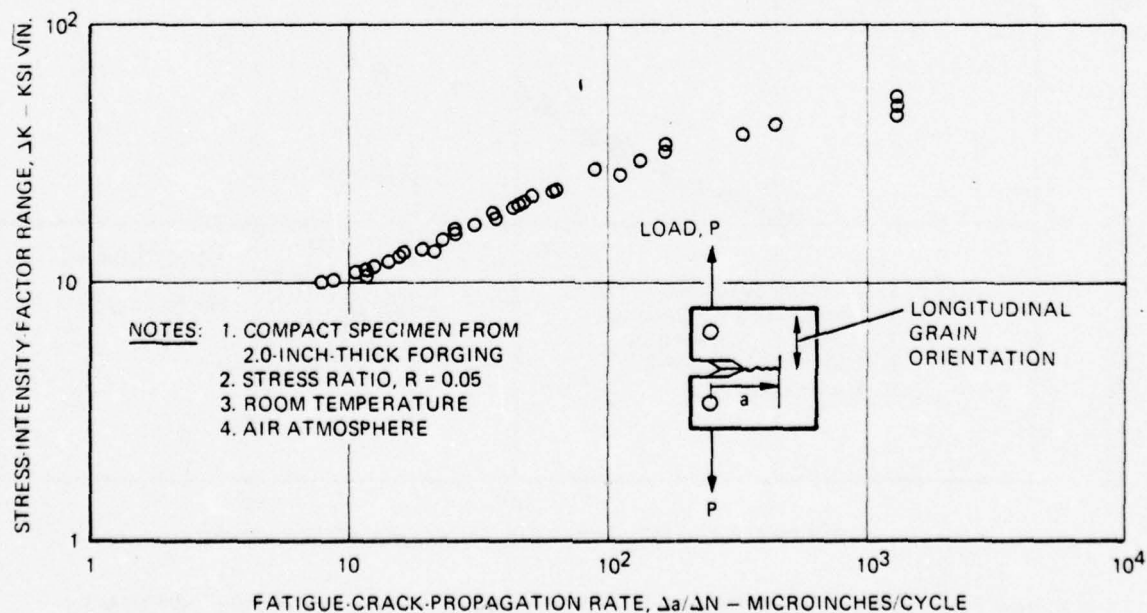


Figure 131. Fatigue-Crack Growth-Rate Performance of Task II Forging, 7475-TMT1 Aluminum Alloy, Specimen 0855.

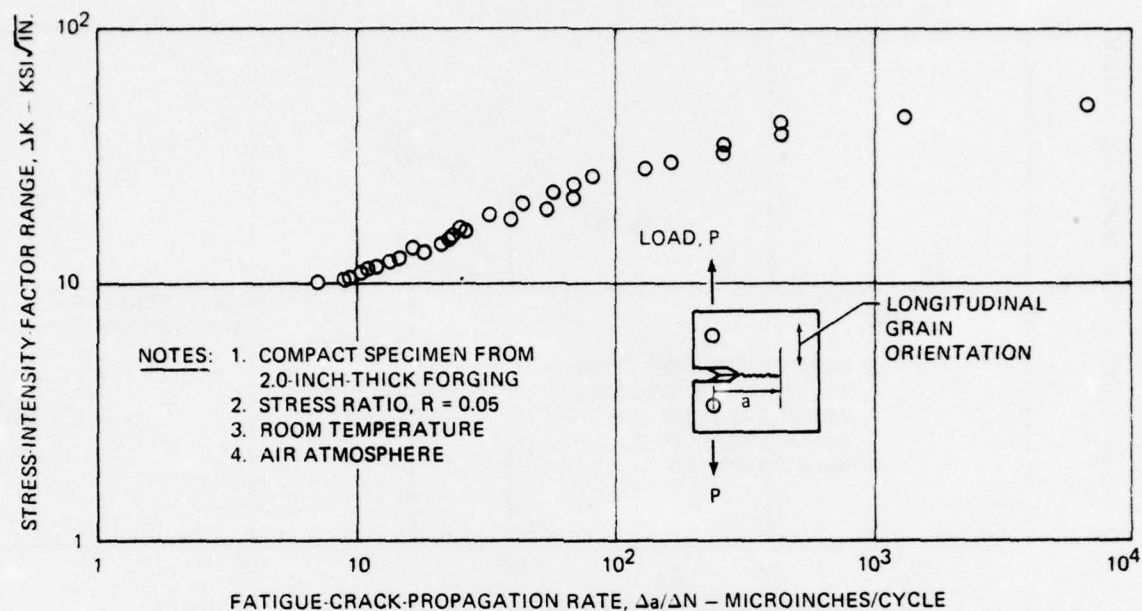


Figure 132. Fatigue-Crack Growth-Rate Performance of Task II Forging, 7475-TMT1 Aluminum Alloy, Specimen 0856.

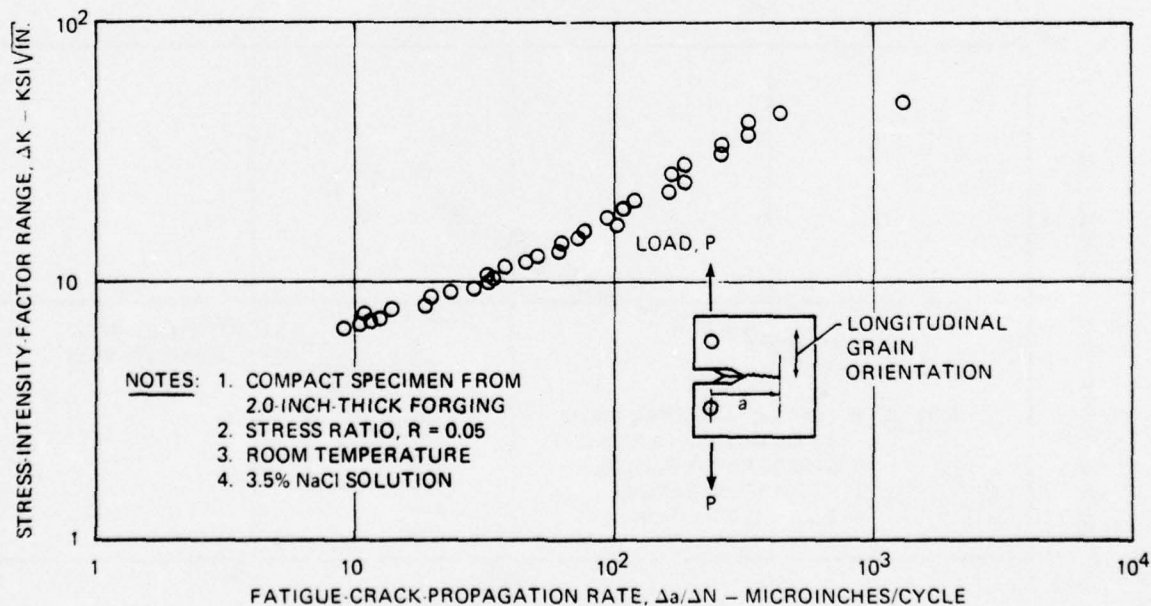


Figure 133. Fatigue-Crack Growth-Rate Performance of Task II Forging, 7475-TMT1 Aluminum Alloy, Specimen 0857.

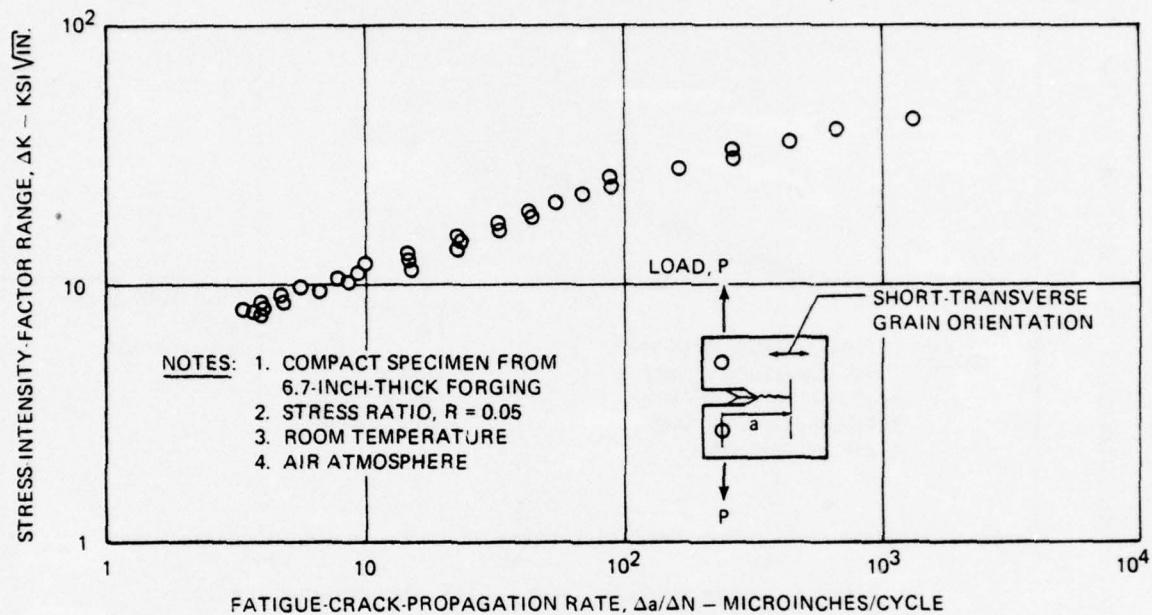


Figure 134. Fatigue-Crack Growth-Rate Performance of Task II Forging, 7475-TMT1 Aluminum Alloy, Specimen 1101.

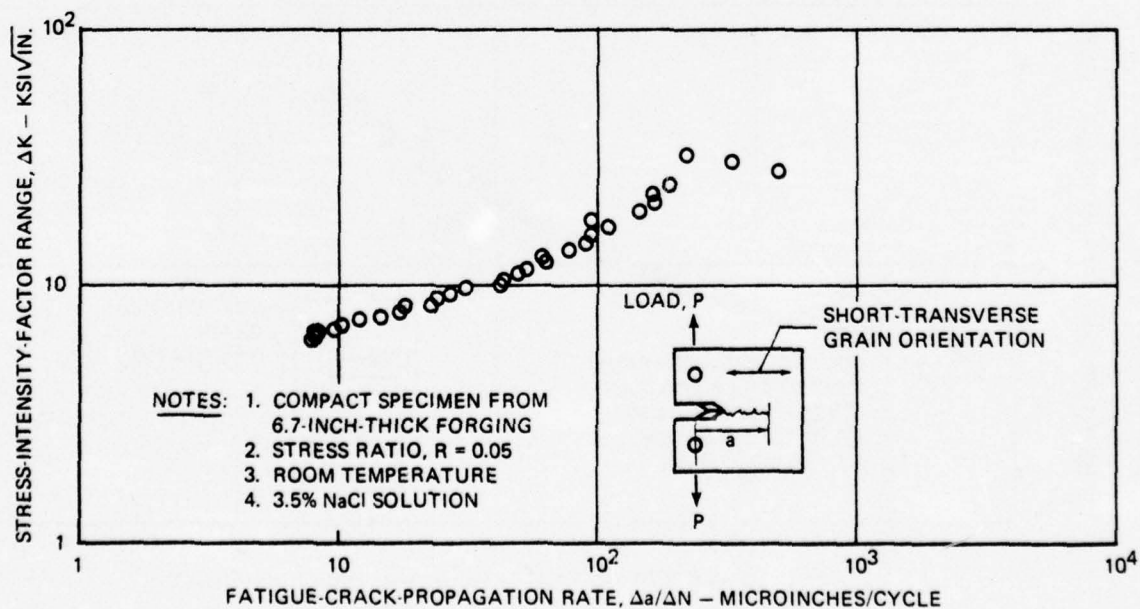


Figure 135. Fatigue-Crack Growth-Rate Performance of Task II Forging, 7475-TMT1 Aluminum Alloy, Specimen 1102.

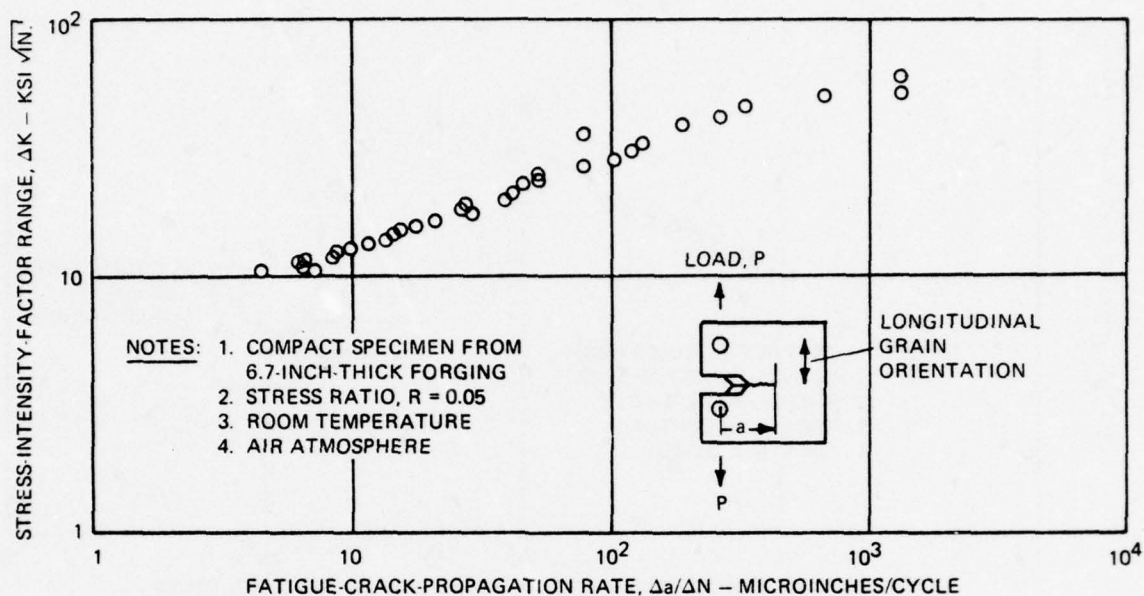


Figure 136. Fatigue-Crack Growth-Rate Performance of Task II Forging, 7475-TMT1 Aluminum Alloy, Specimen 1204.

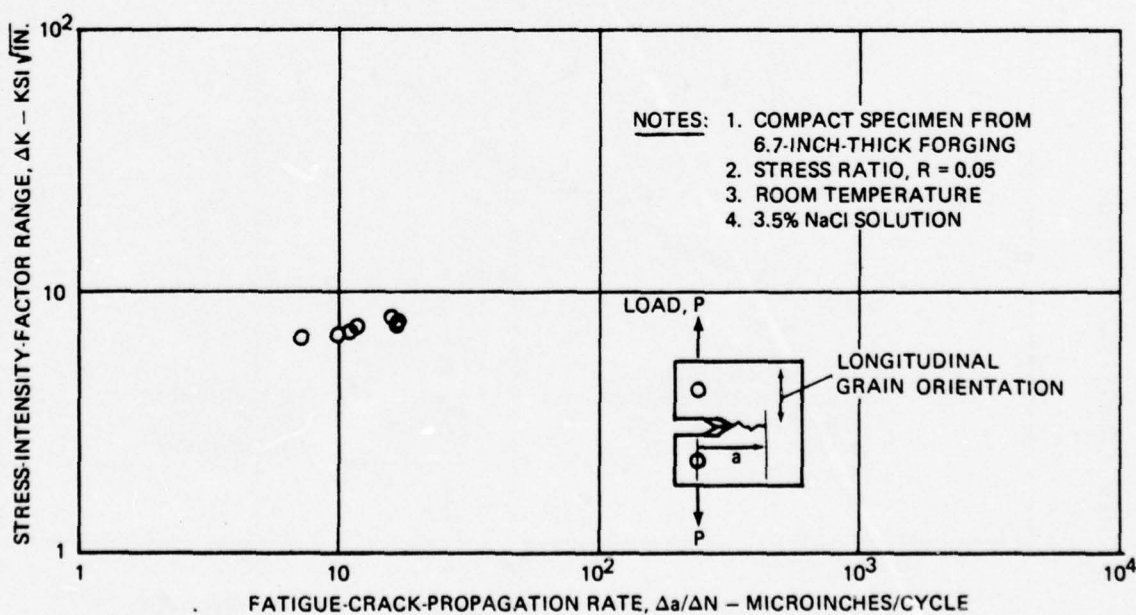


Figure 137. Fatigue-Crack Growth-Rate Performance of Task II Forging, 7475-TMT1 Aluminum Alloy, Specimen 1205.

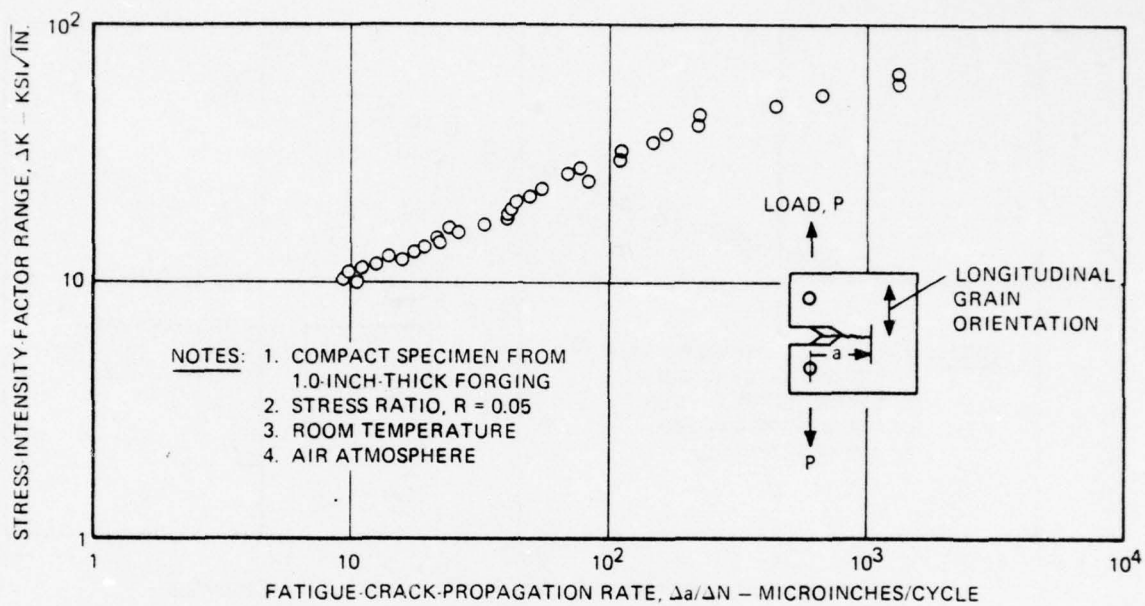


Figure 138. Fatigue-Crack Growth-Rate Performance of Task II Forging, 7475-TMT2 Aluminum Alloy, Specimen 1320.

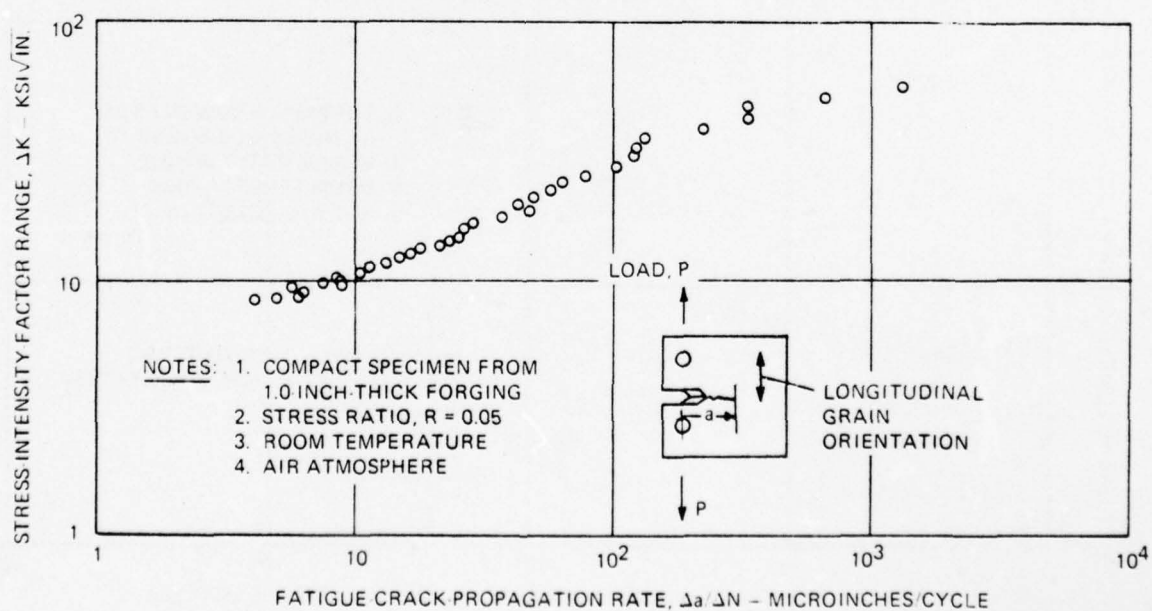


Figure 139. Fatigue-Crack Growth-Rate Performance of Task II Forging, 7475-TMT2 Aluminum Alloy, Specimen 1321.

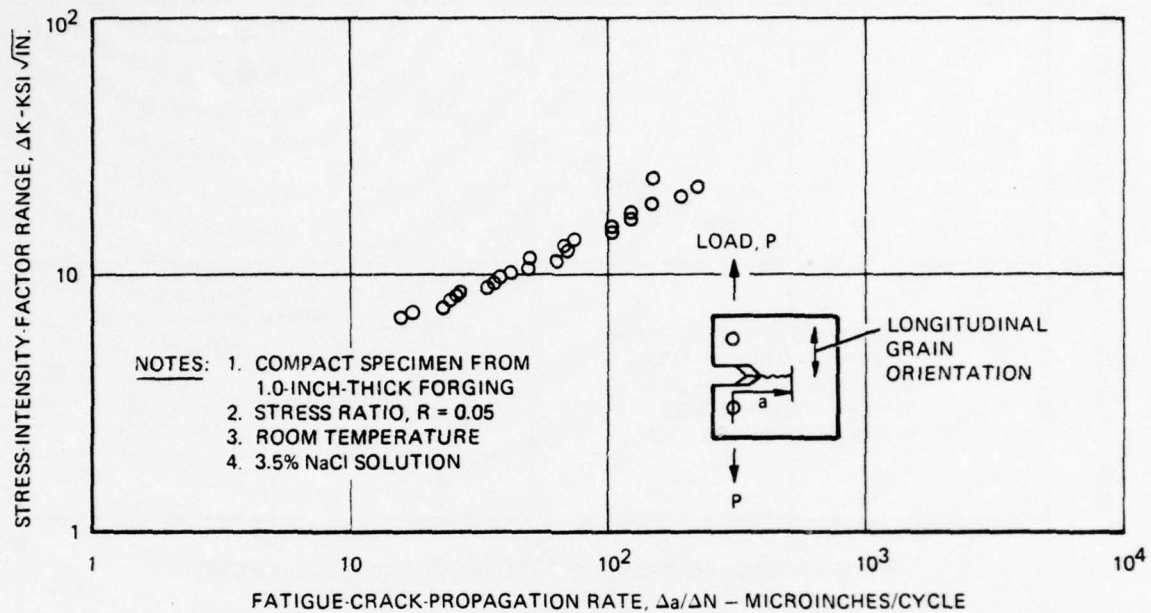


Figure 140. Fatigue-Crack Growth-Rate Performance of Task II Forging, 7475-TMT2 Aluminum Alloy, Specimen 1322.

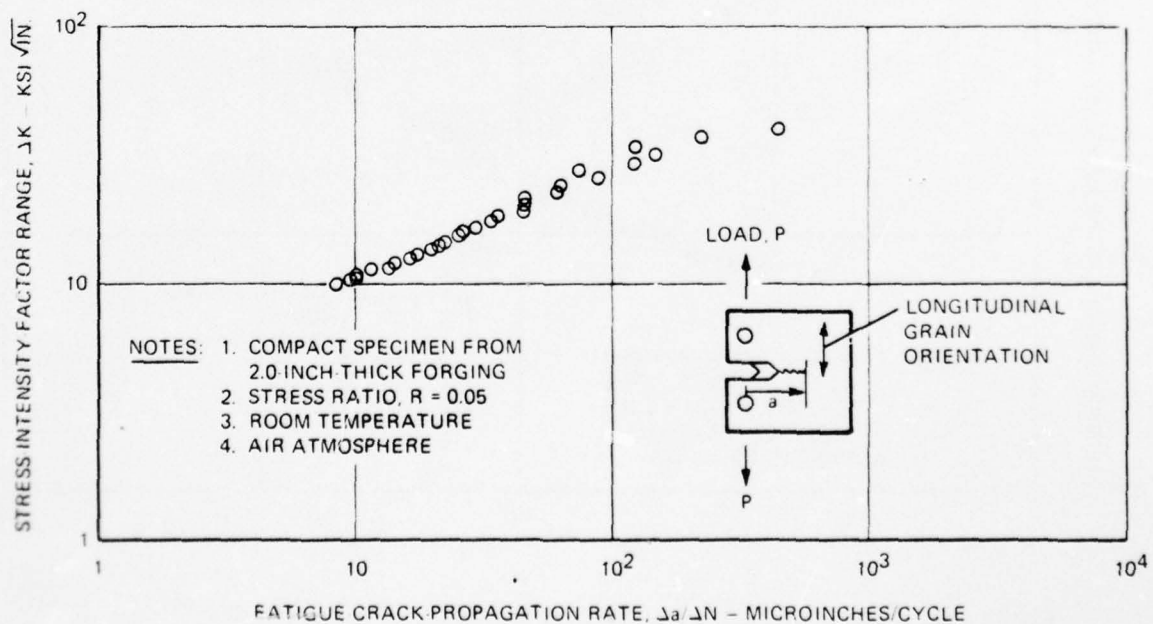


Figure 141. Fatigue-Crack Growth-Rate Performance of Task II Forging, 7475-TMT2 Aluminum Alloy, Specimen 1455.

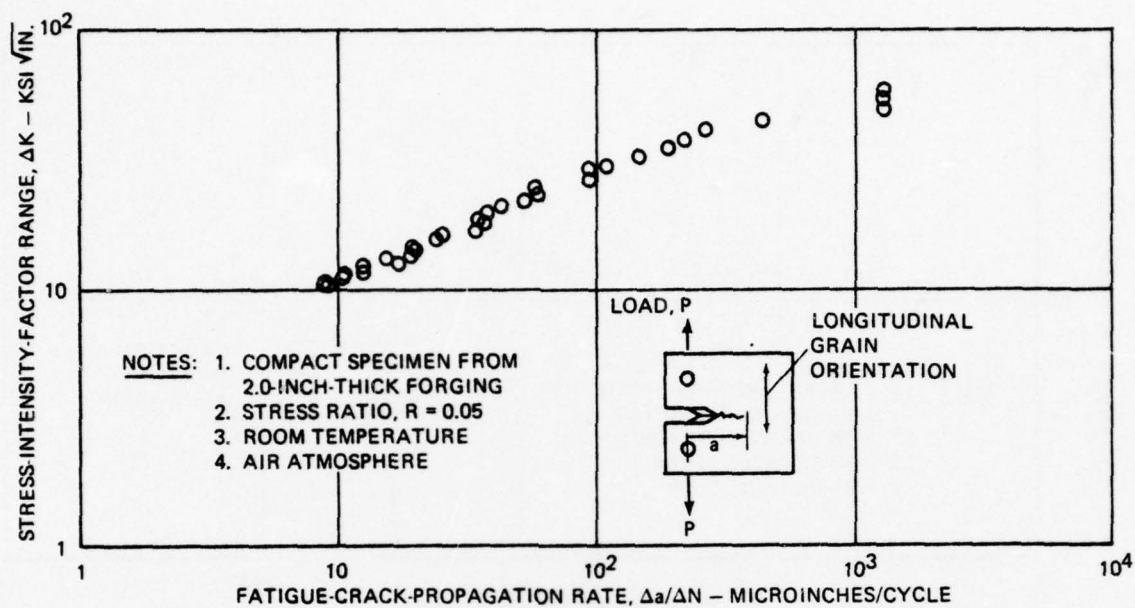


Figure 142. Fatigue-Crack Growth-Rate Performance of Task II Forging, 7475-TMT2 Aluminum Alloy, Specimen 1456.

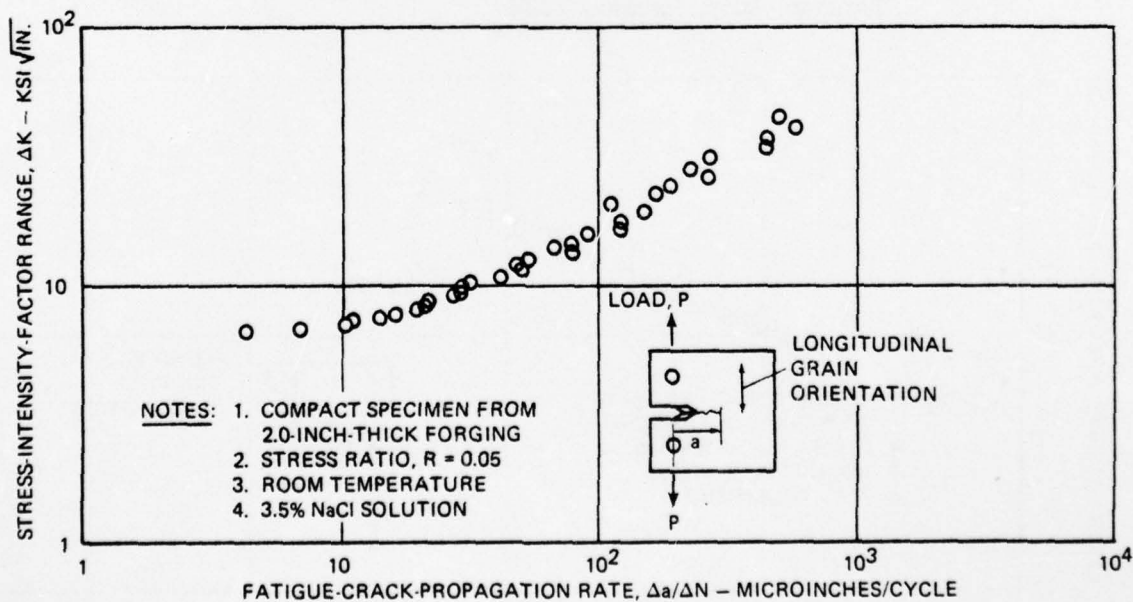


Figure 143. Fatigue-Crack Growth-Rate Performance of Task II Forging, 7475-TMT2 Aluminum Alloy, Specimen 1457.

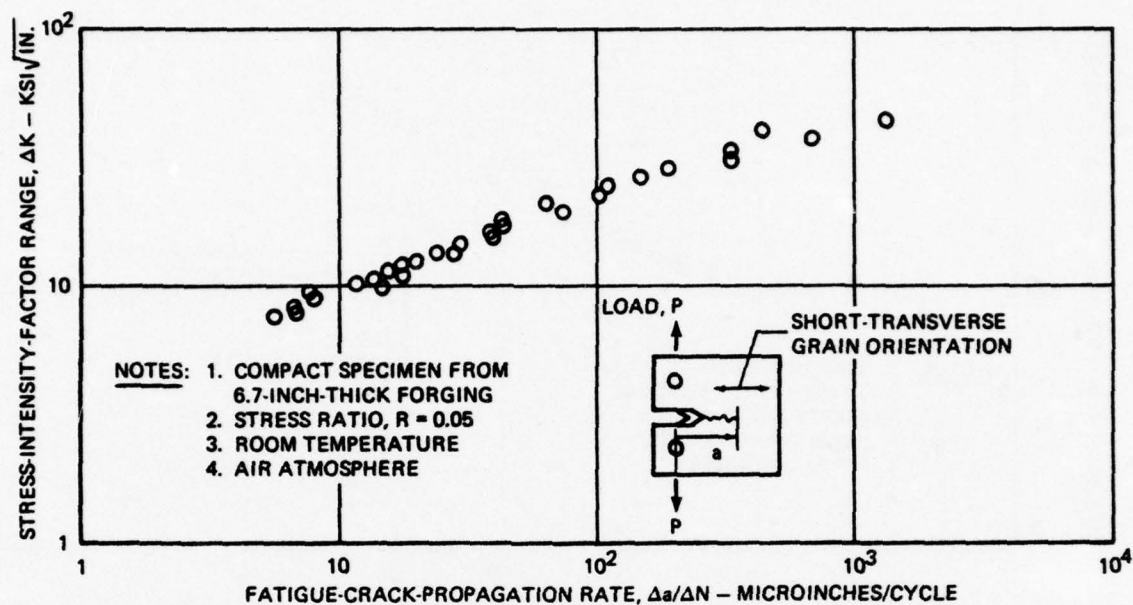


Figure 144. Fatigue-Crack Growth-Rate Performance of Task II Forging, 7475-TMT2 Aluminum Alloy, Specimen 1701.

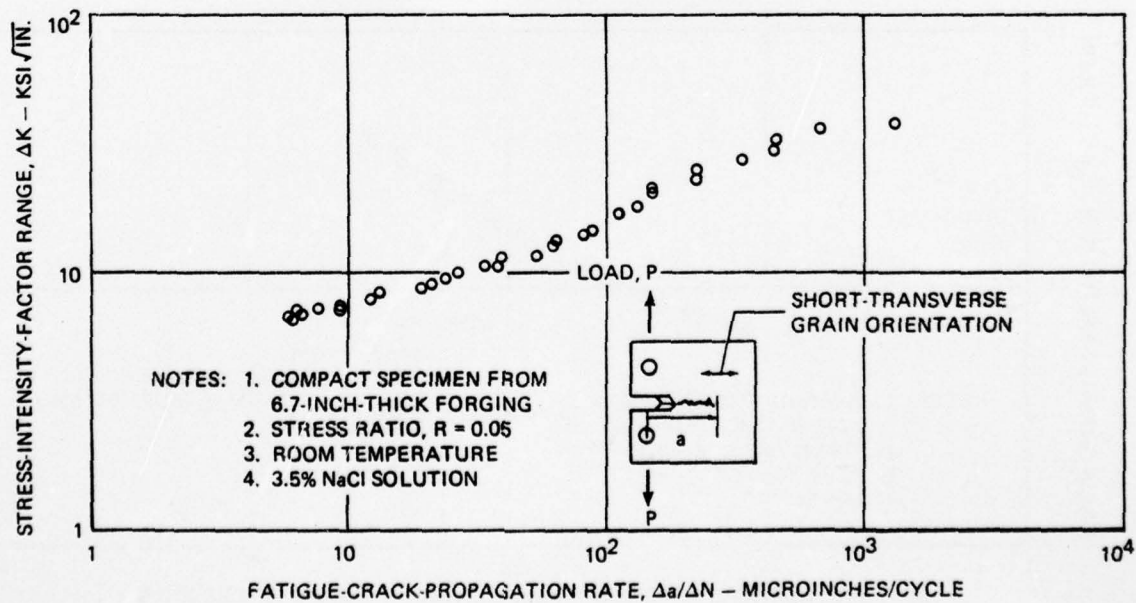


Figure 145. Fatigue-Crack Growth-Rate Performance of Task II Forging, 7475-TMT2 Aluminum Alloy, Specimen 1702.

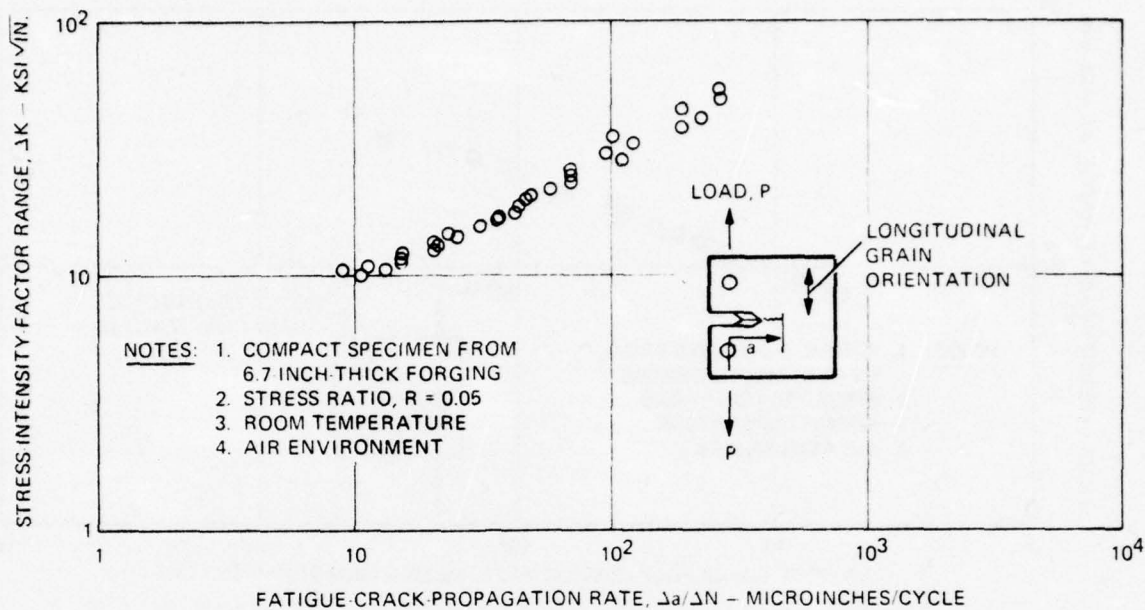


Figure 146. Fatigue-Crack Growth-Rate Performance of Task II Forging, 7475-TMT2 Aluminum Alloy, Specimen 1804.

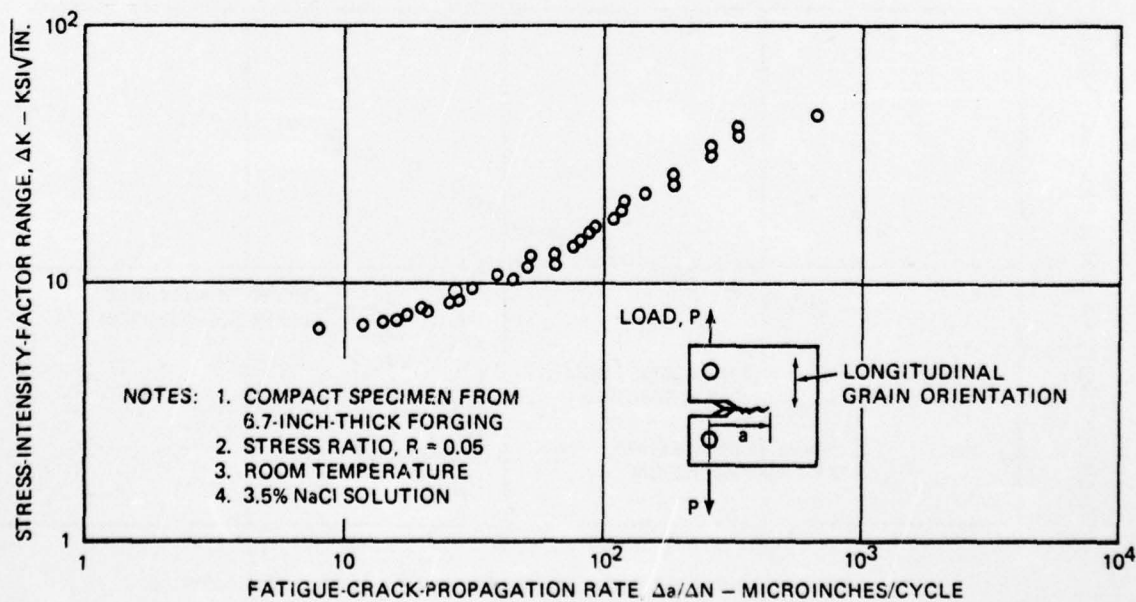


Figure 147. Fatigue-Crack Growth-Rate Performance of Task II Forging, 7475-TMT2 Aluminum Alloy, Specimen 1805.

TABLE 28. COMPARISON OF 7475-TMT CRACK-PROPAGATION RATES
WITH 7075-T73 CRACK-PROPAGATION RATES

Material	Environment	Original Forging Thickness (in.)			
		1	2	6.7	
				Longitudinal	Short transverse
7475-TMT1	Room Air	TMT1 rate is same as 7075-T73; maintains stable growth at higher ΔK 's	TMT1 rate same as 7075-T73	TMT1 slower than 7075-T73; maintains stable growth at higher ΔK 's	TMT1 slower than 7075-T73; maintains stable growth at higher ΔK 's
	3.5% Salt Solution	TMT1 rate is 33% faster than 7075-T73	TMT1 is 100% faster than 7075-T73	—	Rates are the same; TMT1 maintains stable growth rate at higher ΔK 's
7475-TMT2	Room Air	TMT2 is slower than 7075-T73; maintains stable growth rate at higher ΔK 's	TMT2 is 100% slower than 7075-T73	Rates are the same	TMT2 is slower than 7075-T73; maintains stable growth rate at higher ΔK 's
	3.5% Salt Solution	TMT2 is 33% faster than 7075-T73	TMT2 is 100% faster than 7075-T73	TMT2 is 100% faster than 7075-T73	Rates are the same

TABLE 29. COMPARISON OF LONGITUDINAL AND SHORT-TRANSVERSE
CRACK-PROPAGATION RATES IN 6.7-INCH FORGING

Material	Environment	
	Room Air	3.5% Salt Solution
7075-T73	Influence of fracture toughness clearly indicated by instability of crack growth at high ΔK 's	Short-transverse rate is 33% faster than longitudinal rate
7475-TMT1	Short-transverse rate is 14% faster than longitudinal	Short-transverse and longitudinal rates are the same
7475-TMT2	Short-transverse rate slightly faster than longitudinal rate	Short-transverse and longitudinal rates are the same

TABLE 30. RESISTANCE TO CORROSION OF 6.7-INCH-THICK 7075-T7X AND 7475-T7X HAND FORGINGS

S.No.	2nd-Step Aging at 350°F (hr)	Longitudinal Tensile Properties			Elec Cond (% IACS)	Days to Failure of 1/8-In. ϕ Tensile Bars Exposed Stressed to Alternate Immersion (Method 823) for 84 Days											
						Longitudinal Stressed at 45 ksi		Short-Transverse Stressed at 45 ksi		Short-Transverse Stressed at 35 ksi		Short-Transverse Stressed at 25 ksi					
		UTS (ksi)	YS (ksi)	El (%)		Spec L2	Spec L3	Spec L4	Spec N2	Spec N4	Spec N6	Spec N5	Spec N8	Spec N11	Spec N7	Spec N9	
7075 Hand Forging - Unrecrystallized																	
437701-32	2	78.3	68.2	14.0	36.6	OK 84	OK 84	OK 84	F51	F2	F5	F72	OK 84	OK 84	OK 84	OK 84	OK 84
437701-33	4	77.2	67.1	14.0	38.7	OK 84	OK 84	OK 84	OK 84	OK 84	F58	OK 84	OK 84	OK 84	OK 84	OK 84	OK 84
437701-34	6	72.8	61.0	14.0	40.7	OK 84	OK 84	OK 84	OK 84	OK 84	OK 84	OK 84	OK 84	OK 84	OK 84	OK 84	OK 84
437701-35	8	70.2	58.0	14.0	42.1	OK 84	OK 84	OK 84	OK 84	OK 84	OK 84	OK 84	OK 84	OK 84	OK 84	OK 84	OK 84
7475 Hand Forging - Recrystallized Plus Hot-Worked (7475-TMT1)																	
438170-2	2	76.7	68.3	16.0	36.2	OK 84	OK 84	OK 84	F4	F3	F2	F4	F4	F3	F10	OK 84	F9
438170-3	4	75.6	67.0	14.0	38.6	OK 84	OK 84	OK 84	F81	F80	OK 84	OK 84	OK 84	OK 84	OK 84	OK 84	OK 84
438170-4	6	73.9	64.4	16.0	40.1	OK 84	OK 84	OK 84	OK 84	OK 84	OK 84	OK 84	OK 84	OK 84	OK 84	OK 84	OK 84
438170-6	9	73.7	63.2	14.0	40.3	OK 84	OK 84	OK 84	OK 84	OK 84	OK 84	OK 84	OK 84	OK 84	OK 84	OK 84	OK 84
7475 Hand Forging - Recrystallized Plus Hot-Worked (7475-TMT2)																	
438173-2	2	78.6	70.0	14.0	35.2	OK 84	OK 84	OK 84	F3	F2	F2	OK 84	F2	F2	F10	F10	F3
438173-3	4	74.2	65.6	18.0	39.0	OK 84	OK 84	OK 84	F16	F30	F9	F62	F78	F5	OK 84	OK 84	F78
438173-4	6	73.5	64.6	16.0	39.7	OK 84	OK 84	OK 84	F46	OK 84	F80	OK 84	OK 84	OK 84	OK 84	OK 84	OK 84
438173-6	9	70.2	59.0	18.0	40.5	OK 84	OK 84	OK 84	OK 84	OK 84	OK 84	OK 84	OK 84	OK 84	OK 84	OK 84	OK 84
7475 Hand Forging - Unrecrystallized																	
438176-2	2	82.9	75.6	12.0	35.2	OK 84	OK 84	OK 84	F2	F2	F2	F2	F2	F2	F2	F10	OK 84
438176-3	4	77.0	70.7	6.0	37.7	OK 84	OK 84	OK 84	F10	F3	OK 84	F24	OK 84	F84	OK84	F83	OK 84
438176-4	6	75.9	67.6	10.0	38.9	OK 84	OK 84	OK 84	F30	F10	Not exposed	F25	F37	Not exposed	F83	OK 84	OK 84
438176-6	9	67.6	60.0	6.0	40.4	OK 84	OK 84	OK 84	OK 84	OK 84	OK 84	OK 84	Not exposed	OK 84	OK 84	OK 84	OK 84

NOTES:

1. Forgings heat-treated, quenched in cold water, aged 24 hours at 250°F; plus indicated time at 350°F as 2-in.-thick sawed sections.

2. 7075 heat-treated at 880°F, 7475 heat-treated at 960°F.

3. Yield strength = 0.2% offset.

NOTES: 1. Forgings heat-treated, quenched in cold water, aged 24 hours at 250°F, plus indicated time at 350°F as 2-in.-thick sawed sections.
2. 7075 heat-treated at 880°F, 7475 heat-treated at 960°F.
3. Yield strength = 0.2% offset.

TABLE 31. RESISTANCE TO CORROSION OF 2-INCH-THICK 7075-T7X AND 7475-T7X HAND FORGINGS

S.No.	2nd-Step Aging at 350°F (hr)	Longitudinal Tensile Properties			Elec Cond (% IACS)	Days to Failure of 1/8-In. ϕ Tensile Bars Exposed Stressed to Alternate Immersion (Method 823) for 84 Days											
						Longitudinal Stressed at 45 ksi			Short-Transverse Stressed at 45 ksi			Short-Transverse Stressed at 35 ksi			Short-Transverse Stressed at 25 ksi		
		UTS (ksi)	YS (ksi)	El (%)		Spec L2	Spec L3	Spec L4	Spec N2	Spec N4	Spec N6	Spec N5	Spec N8	Spec N11	Spec N1	Spec N7	Spec N9
7075 Hand Forging - Unrecrystallized																	
437701-22	2	83.7	73.4	12.0	36.0	OK 84	OK 84	OK 84	F3	F34	F43	F72	F10	F72	F10	F3	OK 84
437701-23	4	78.0	69.0	14.0	39.2	OK 84	OK 84	OK 84	OK 84	OK 84	OK 84	OK 84	OK 84	OK 84	OK 84	OK 84	OK 84
437701-24	6	76.3	65.4	14.0	39.6	OK 84	OK 84	OK 84	OK 84	OK 84	OK 84	OK 84	OK 84	OK 84	OK 84	OK 84	OK 84
437701-25	8	73.3	61.7	16.0	41.0	OK 84	OK 84	OK 84	OK 84	OK 84	OK 84	OK 84	OK 84	OK 84	OK 84	OK 84	OK 84
7475 Hand Forging - Recrystallized Plus Hot-Worked (7475-TMT1)																	
438169-2	2	82.0	74.9	14.0	37.2	OK 84	OK 84	OK 84	F2	F2	F2	F2	F2	OK 84	F3	F3	F3
438169-3	4	79.6	71.0	16.0	39.3	OK 84	OK 84	OK 84	F46	F54	F6	F60	OK 84	F52	OK 84	OK 84	OK 84
438169-4	6	79.4	70.2	16.0	40.7	OK 84	OK 84	OK 84	F66	F60	F58	F71	OK 84	F80	OK 84	OK 84	OK 84
438169-6	9	76.0	65.6	14.0	41.5	OK 84	OK 84	OK 84	OK 84	OK 84	OK 84	OK 84	OK 84	OK 84	OK 84	OK 84	OK 84
7475 Hand Forging - Recrystallized Plus Hot-Worked (7475-TMT2)																	
438172-2	2	80.3	72.0	14.0	38.0	OK 84	OK 84	OK 84	F2	F2	F2	F3	F2	F3	F2	F3	OK 84
438172-3	4	80.7	71.0	14.0	40.1	OK 84	OK 84	OK 84	F4	F5	F33	F57	F58	F61	OK 84	OK 84	OK 84
438172-4	6	76.4	67.3	16.0	40.5	OK 84	OK 84	OK 84	F54	OK 84	F27	OK 84	F64	F58	OK 84	OK 84	OK 84
438172-6	9	75.1	63.9	14.0	42.3	OK 84	OK 84	OK 84	F57	Defect spec	F80	OK 84	OK 84	OK 84	OK 84	OK 84	OK 84
7475 Hand Forging - Unrecrystallized																	
438175-2	2	82.3	74.6	16.0	36.6	OK 84	OK 84	OK 84	F3	F3	F3	F8	F30	F30	OK 84	OK 84	OK 84
438175-3	4	79.6	71.7	16.0	39.7	OK 84	OK 84	OK 84	F19	F24	F5	F26	F30	F30	F57	F58	OK 84
438175-4	6	75.2	65.3	16.0	40.6	OK 84	OK 84	OK 84	Not exposed	Not exposed	OK 84	OK 84	OK 84	F30	OK 84	OK 84	OK 84
438175-6	9	73.4	63.9	16.0	42.2	OK 84	OK 84	OK 84	OK 84	OK 84	OK 84	OK 84	OK 84	F84	OK 84	OK 84	OK 84

NOTES:

1. Forgings heat-treated, quenched in cold water, aged 24 hours at 250°F plus indicated time at 350°F.

2. 7075 forging heat-treated at 880°F, 7475 forgings heat-treated at 960°F.

3. Yield strength = 0.2% offset.

NOTES: 1. Forgings heat-treated, quenched in cold water, aged 24 hours at 250°F plus indicated time at 350°F.
2. 7075 forging heat-treated at 880°F, 7475 forgings heat-treated at 960°F.
3. Yield strength = 0.2% offset.

**TABLE 32. RESISTANCE TO CORROSION OF 1-INCH-THICK
7075-T7X AND 7475-T7X HAND FORGINGS**

S.No.	2nd-Step Aging at 350°F (hr)	Longitudinal Tensile Properties			Elec Cond (% IACS)	Days to Failure of Specimens Exposed Stressed to Alternate Immersion (Method 823) for 84 Days							
						Longitudinal 1/8-In. ϕ Tensile Bars Stressed at 45 ksi			Short-Transverse Stressed at 45 ksi		0.75-In. ϕ C-Rings Stressed at 35 ksi		
		UTS (ksi)	YS (ksi)	El (%)		Spec L2	Spec L3	Spec L4	Spec C1	Spec C2	Spec C3	Spec C4	
7075 Hand Forging – Unrecrystallized													
437701-12	2	82.2	72.9	14.0	36.3	OK 84	OK 84	OK 84	OK 84 ²	OK 84 ²	Not exposed	Not exposed	
437701-13	4	79.9	69.5	16.0	37.4	OK 84	OK 84	OK 84	OK 84 ¹	OK 84 ¹	Not exposed	Not exposed	
437701-14	6	78.7	68.0	14.0	38.4	OK 84	OK 84	OK 84	OK 84 ¹	OK 84 ¹	Not exposed	Not exposed	
437701-15	8	74.5	62.7	16.0	40.6	OK 84	OK 84	OK 84	OK 84	OK 84	Not exposed	Not exposed	
7475 Hand Forging – Recrystallized Plus Hot-Worked (7475-TMT1)													
438168-2	2	81.9	74.6	16.0	37.9	OK 84	OK 84	OK 84	OK 84 ¹	OK 84 ¹	OK 84 ²	OK 84 ¹	
438168-3	4	81.0	72.7	16.0	40.0	OK 84	OK 84	OK 84	OK 84	OK 84	OK 84	OK 84 ¹	
438168-4	6	78.5	69.3	16.0	41.0	OK 84	OK 84	OK 84	OK 84	OK 84	OK 84	OK 84	
438168-6	9	74.3	65.4	18.0	41.9	OK 84	OK 84	OK 84	OK 84	OK 84	OK 84	OK 84	
7475 Hand Forging-Recrystallized Plus Hot-Worked (7475-TMT2)													
438171-2	2	80.0	73.4	16.0	38.3	OK 84	OK 84	OK 84	F51DA	F51DA	OK 84 ²	OK 84 ²	
438171-3	4	79.0	71.6	16.0	40.2	OK 84	OK 84	OK 84 ²	OK 84	OK 84 ¹	OK 84 ¹	OK 84	
438171-4	6	77.0	67.8	16.0	41.0	OK 84	OK 84	OK 84	OK 84	OK 84	OK 84	OK 84	
438171-6	9	74.6	64.4	16.0	42.1	OK 84	OK 84	OK 84	OK 84	OK 84	OK 84	OK 84	
7475 Hand Forging – Unrecrystallized													
438174-2	2	83.8	76.6	14.0	37.0	OK 84	OK 84	OK 84	OK 84 ²	OK 84 ¹	Not exposed	Not exposed	
438174-3	4	80.2	72.4	14.0	39.1	OK 84	OK 84	OK 84	OK 84	OK 84	Not exposed	Not exposed	
438174-4	6	77.4	69.0	18.0	40.1	OK 84	OK 84	OK 84	OK 84	OK 84	OK 84	OK 84	
438174-6	9	74.8	64.9	18.0	41.3	OK 84	OK 84	OK 84	OK 84	OK 84	OK 84	OK 84	
NOTES: 1. Specimen did not fail but contained severe directional pitting. 2. Specimen did not fail but contained small directional cracks. 3. Forgings heat-treated, quenched in cold water, aged 24 hours at 250°F plus indicated time at 350°F. 4. 7075 forging heat-treated at 880°F, 7475 forgings heat-treated at 960°F. 5. Yield strength = 0.2% offset.													

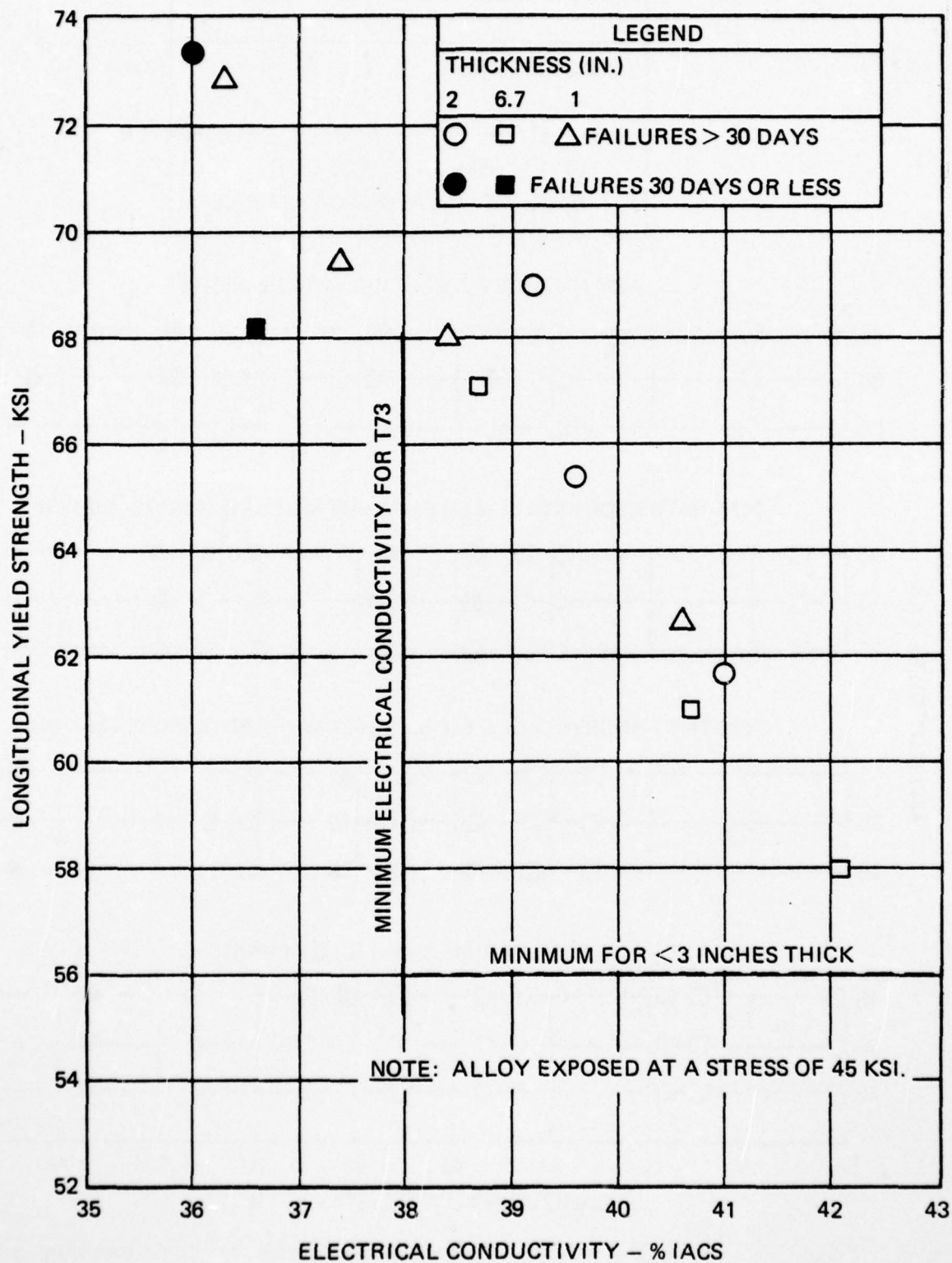


Figure 148. Longitudinal Yield Strength Versus Electrical Conductivity for Unrecrystallized 7075 Aluminum Alloy.

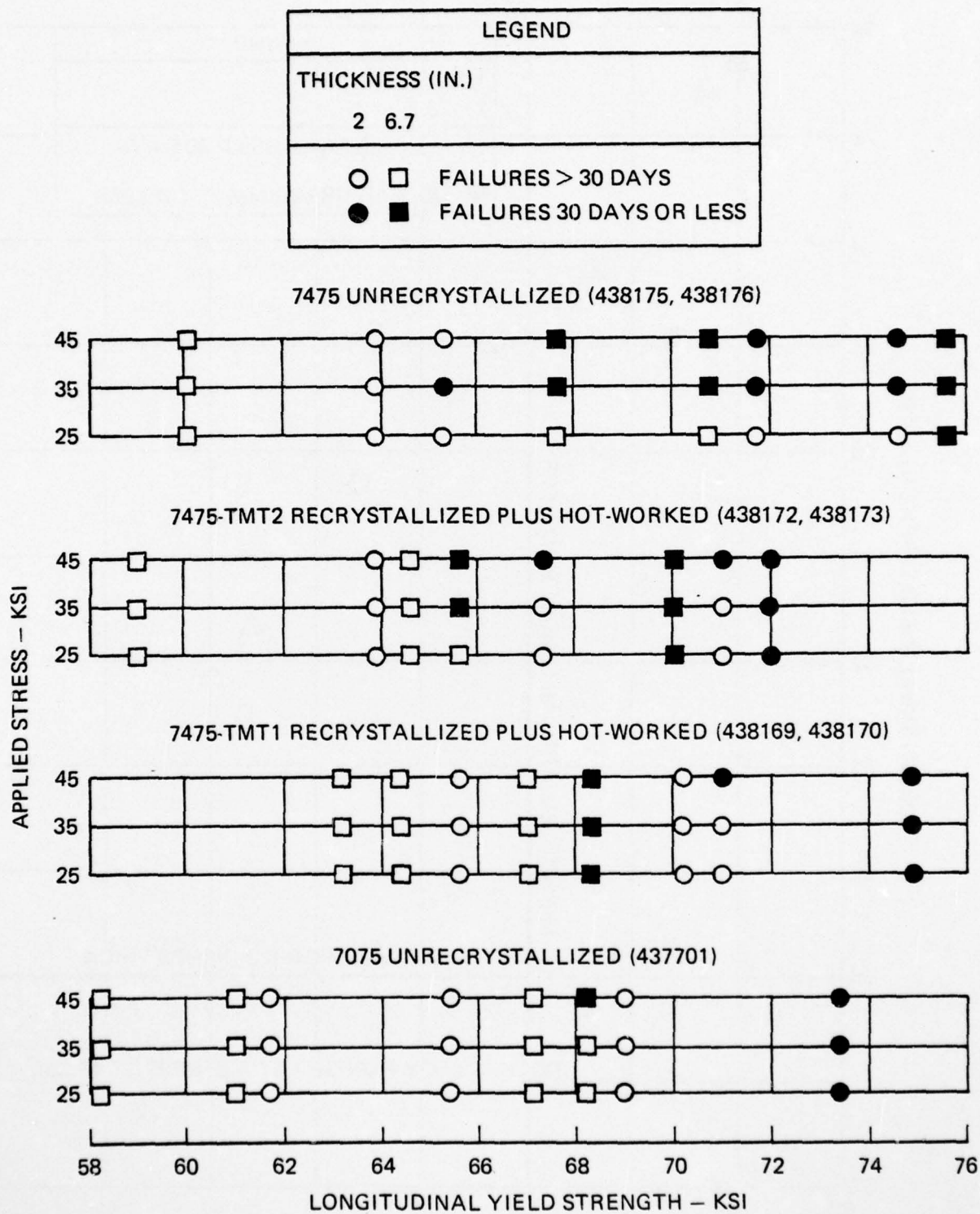


Figure 149. Applied Stress Versus Longitudinal Yield Strength for Aluminum Alloy.

LEGEND		
THICKNESS (IN.)		
2	6.7	
○	■	FAILURES > 30 DAYS
●	■	FAILURES 30 DAYS OR LESS

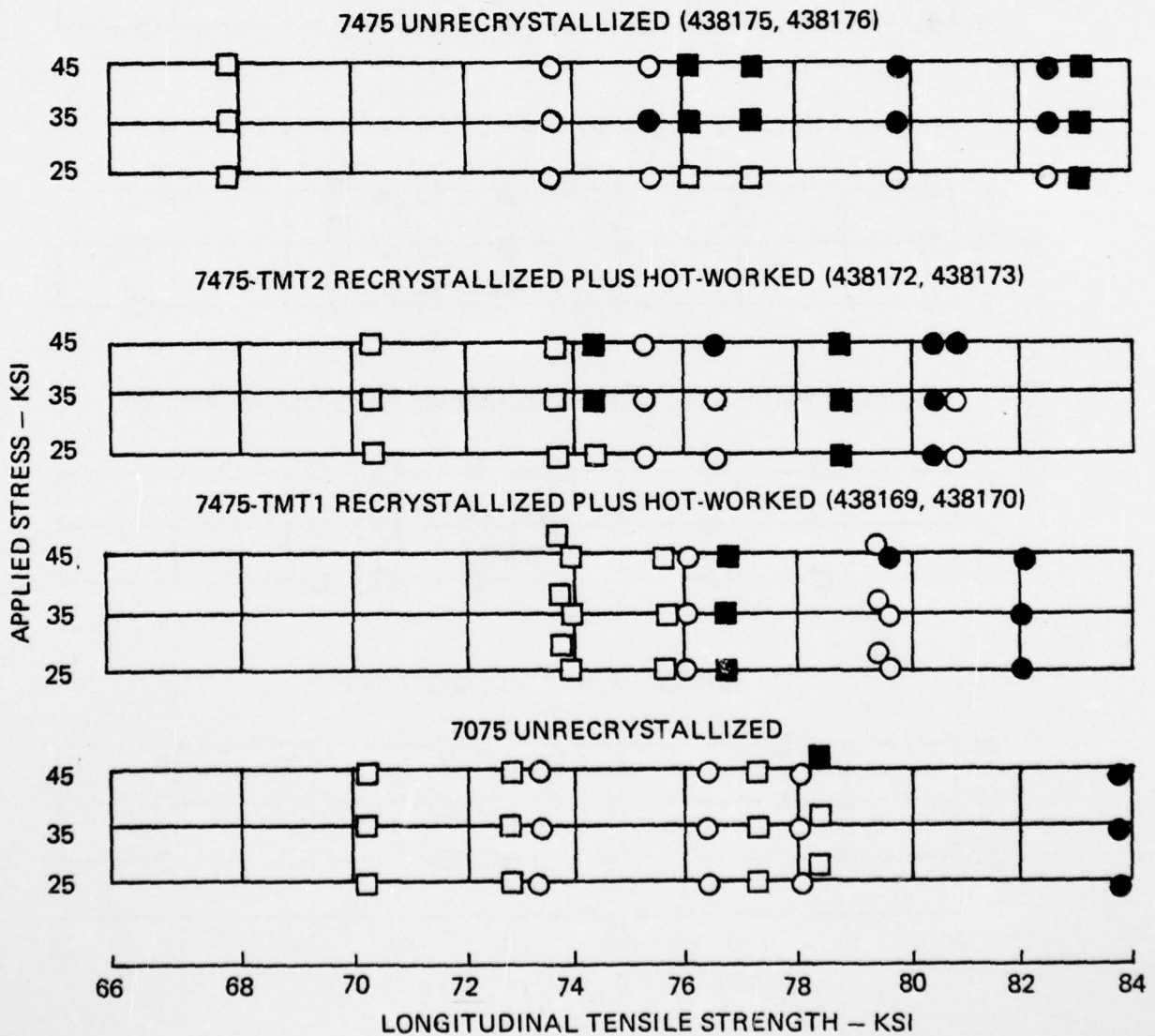


Figure 150. Applied Stress Versus Longitudinal Tensile Strength for Aluminum Alloy.

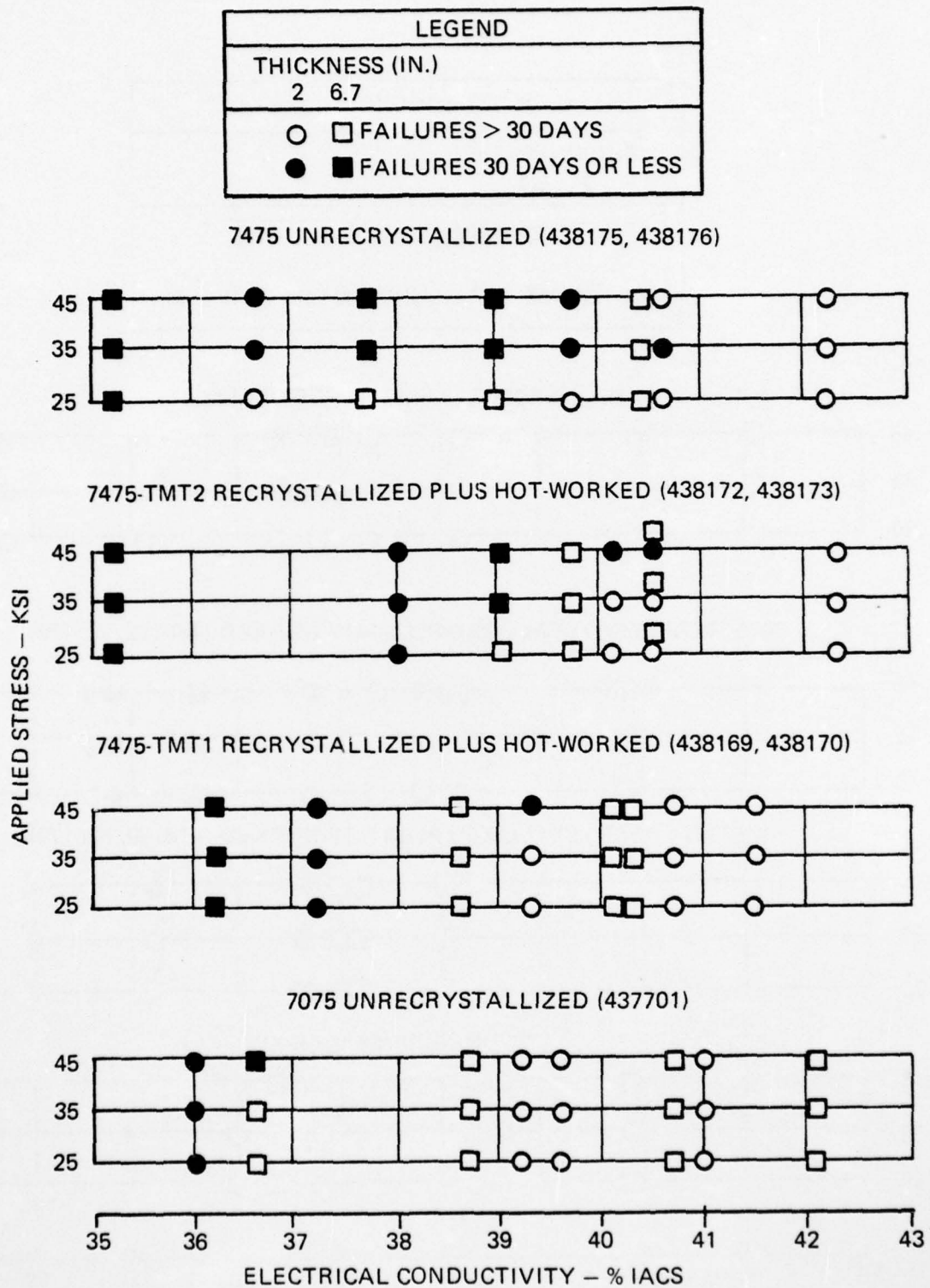


Figure 151. Applied Stress Versus Electrical Conductivity for Aluminum Alloy.

TASK IV – DATA ANALYSIS AND EVALUATION

The objectives of this task are to analyze and evaluate the metallurgical and mechanical-properties data developed in the previous tasks and to assess the impact of improved mechanical properties on the weight and cost of helicopter components.

The properties obtained with the advanced-alloy/process combinations 7475-TMT1 and 7475-TMT2 were compared with the properties measured from the conventionally processed 7075-T73, and in some instances with 7075-T73 properties available in published literature. The advanced-alloy/process combinations are ranked in Table 33 with respect to their ability to improve tensile, fatigue, fracture, and stress-corrosion-resistance properties.

TABLE 33. RANKING OF 7475-TMT ALLOY FORGINGS

Basis of Comparison	7475-TMT1		7475-TMT2	
Tensile Properties	Longitudinal	A	Longitudinal	B
	Short-transverse	B	Short-transverse	A
Fatigue Properties		A		B
Fatigue-Crack-Propagation Properties	Low ΔK	A	Low ΔK	B
	High ΔK	B	High ΔK	A
Fracture Properties		A		B
Stress-Corrosion Resistance		A		B
NOTE: A is superior to B.				

The advantages of using advanced processes to produce forgings for helicopter components will be demonstrated by example.

In designing helicopter structural components, the selection of a material involves considerations of cost, weight, reliability, and maintainability as well as basic material properties. Weight is a primary concern and results directly from satisfying structural requirements for static strength, fatigue strength, and failsafe or damage-tolerance strength.

Many helicopter structural components are aluminum forgings which are generally sized first by fatigue-strength requirements. Advanced processes for aluminum forgings possessing increased fatigue strength have potential for weight savings in direct proportion to that increase in fatigue strength. This can be demonstrated for the YUH-61A horizontal-stabilizer spar fitting, part no. 179-25101, shown in Figure 152. This component is sized for fatigue strength and the critical areas are the lugs. The fitting lug is designed for 5,000 hours of fatigue life using 7075-T73 forging. Detailed calculations presented in Appendix E show that a 5-percent increase in the design-allowable fatigue strength results in a 5-percent reduction in component weight (see Figure 153).

Potential weight savings for helicopter components sized to damage-tolerance requirements are possible by using the 7475-TMT1 or 7475-TMT2 advanced-alloy/process combination. Consider the YUH-61A antitorque-rotor collective-pitch slider, part no. 179-57370, shown in Figure 154. The pitch slider can be designed to be failsafe if equipped with a fatigue-crack-detection device which provides a visible indication (failure warning) when a small crack exists. Assume the device is examined prior to each flight and that there is a criterion requiring the partially failed component to be capable of sustaining flight loads for 30 hours subsequent to the initial failure warning.

In designing the component for these requirements, two mechanical properties are of prime concern. First, the fatigue-crack propagation-rate properties determine how fast the fatigue crack grows. Second, the fracture-toughness property determines the critical crack length which the component can be expected to sustain under the maximum load anticipated in flight.

The predicted performance of the pitch slider is shown in Figure 155 and is based on the properties measured in Task III for conventional 7075-T73 and 7475-TMT2 alloy for fatigue-crack-propagation rate (Figures 127 and 146) and for fracture toughness (Table 21).

For this example, crack growth is predicted by using an RMS stress level of $865 \pm 1,605$ psi with the crack model for a hollow cylinder and the Paris relationship for crack-growth rate. The computation procedure is detailed in Appendix F.

From the comparison shown in Figure 155, it can be seen that an improvement is possible with TMT forgings. This improvement can be used to provide additional reliability or to effect a weight saving and meet the original reliability. The weight saving as a function of improvement in fracture properties is shown in Figure 156. Computations are shown in Appendix F.

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IMPROVEMENT OF HELICOPTER FORGINGS BY CONTROLLED SOLIDIFICATION--ETC(U)
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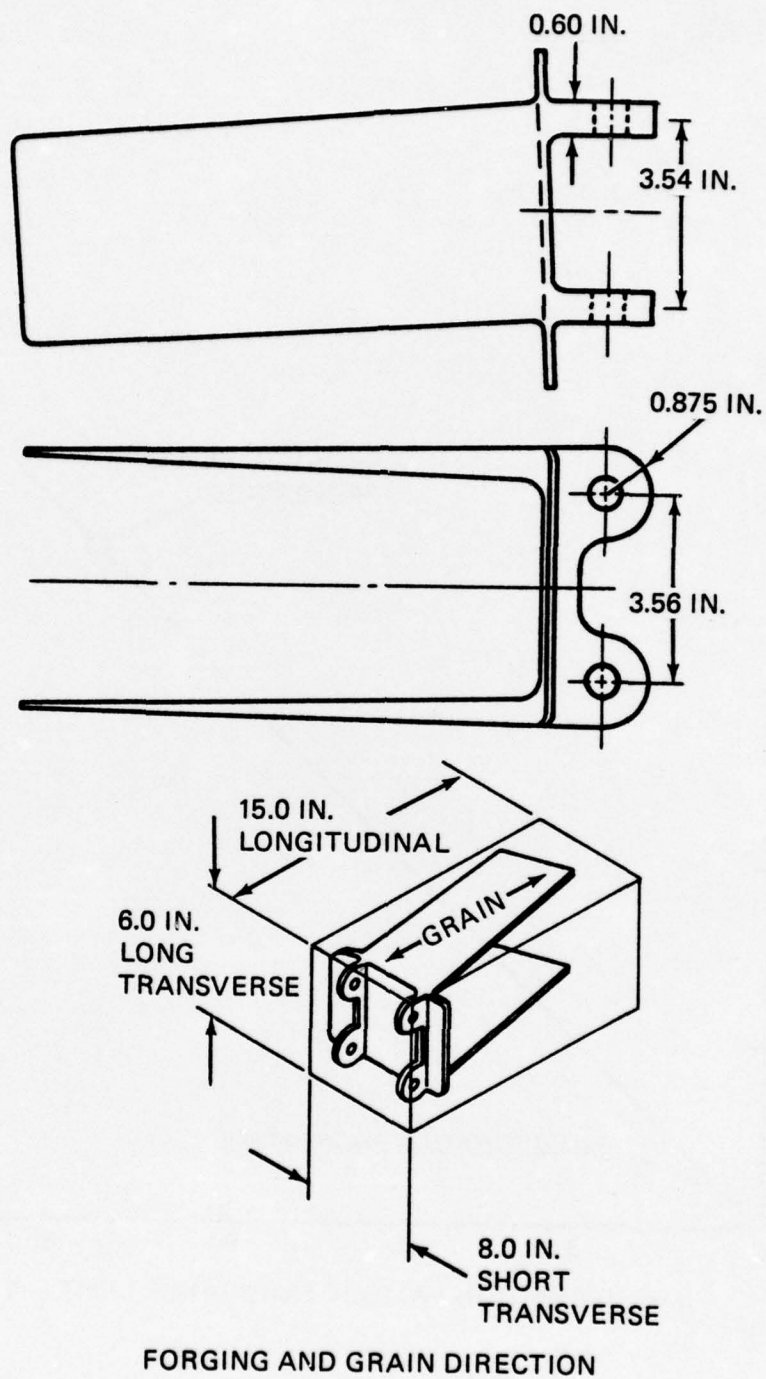


Figure 152. Horizontal Stabilizer Spar Fitting for YUH-61A UTTAS.

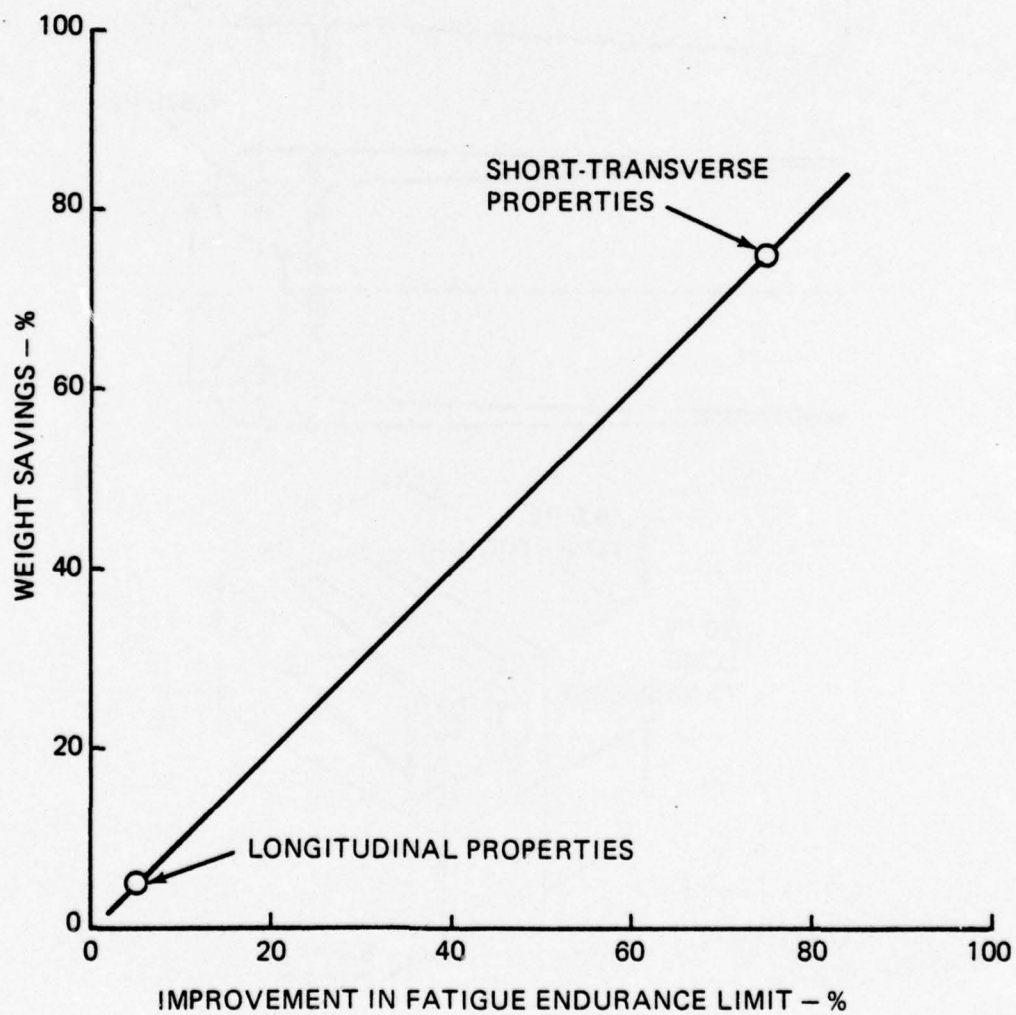


Figure 153. Weight Savings Available Through Improved Fatigue Properties.

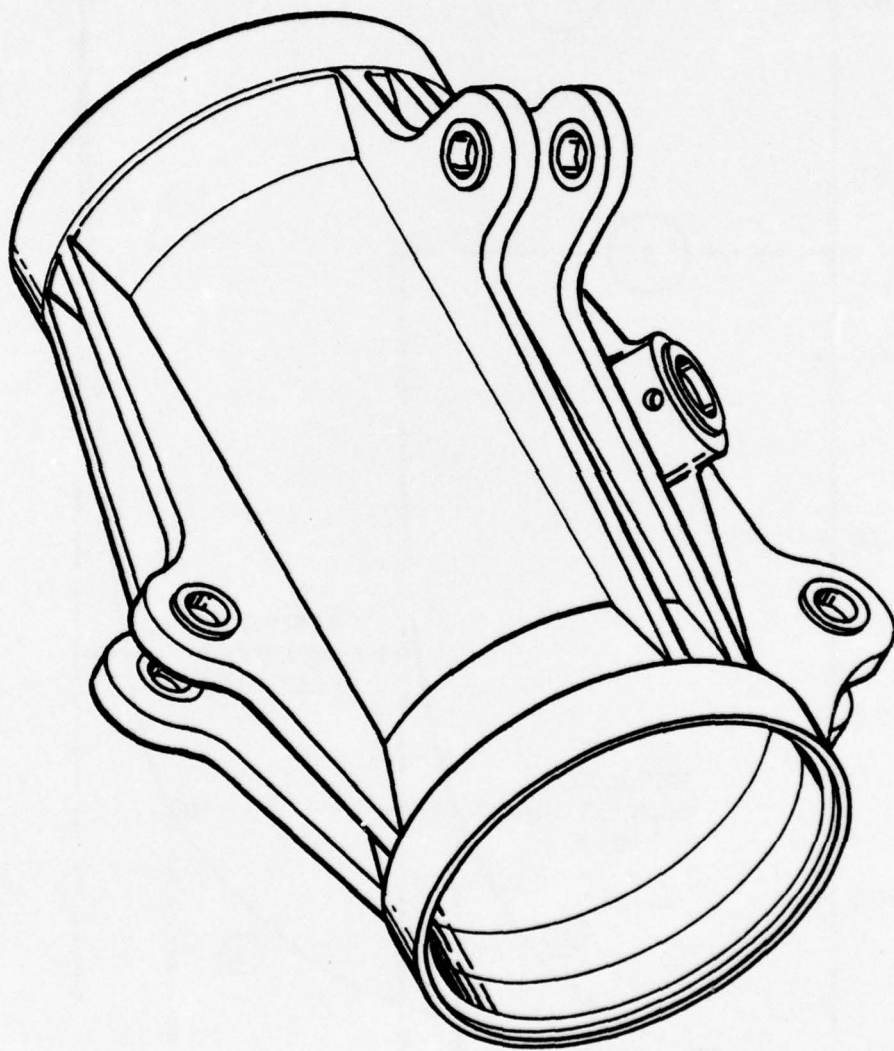


Figure 154. Collective Pitch Slider for Antitorque Rotor on YUH-61A UTTAS.

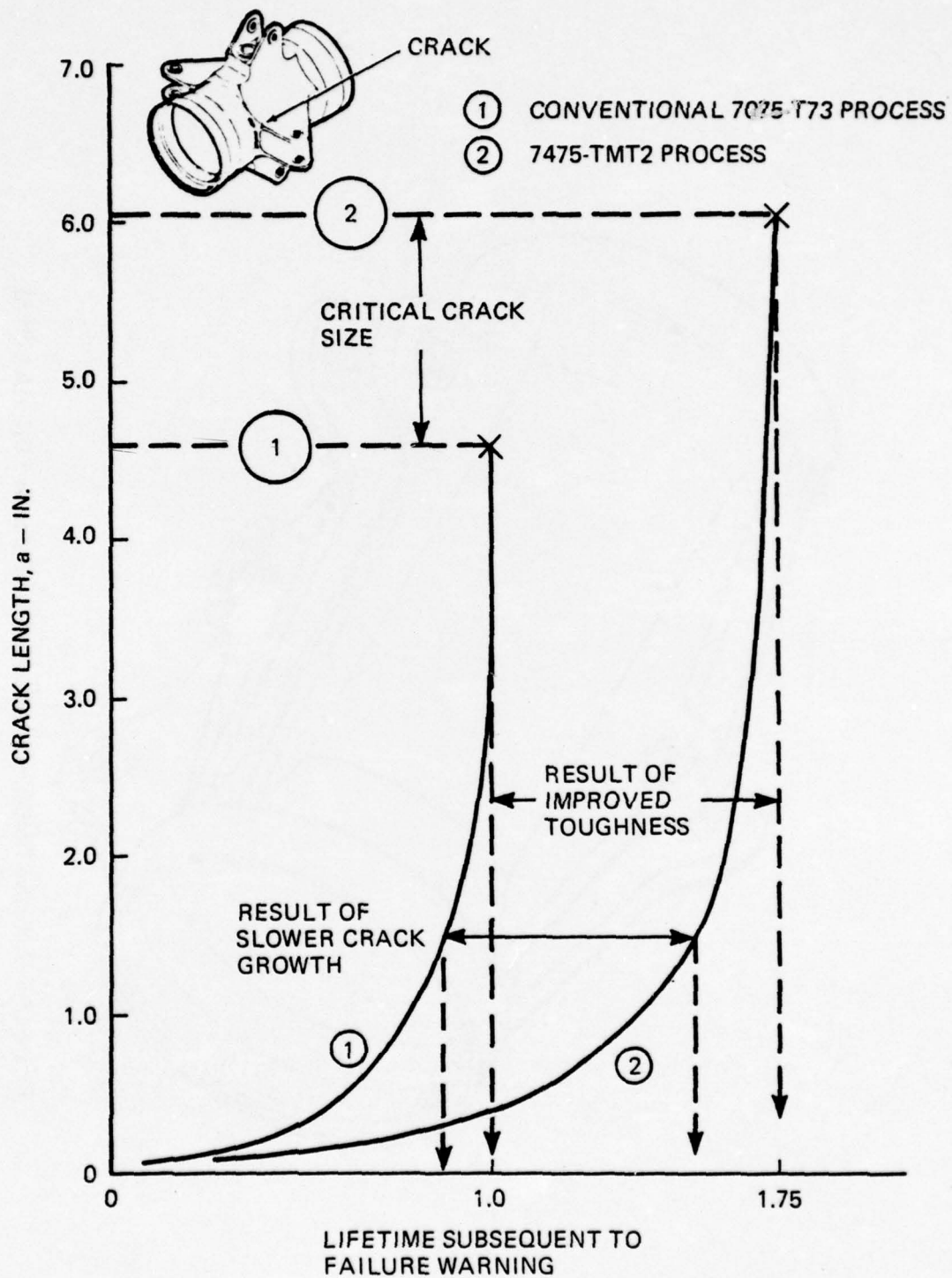


Figure 155. Improved Failsafety Through Enhanced Fracture Properties.

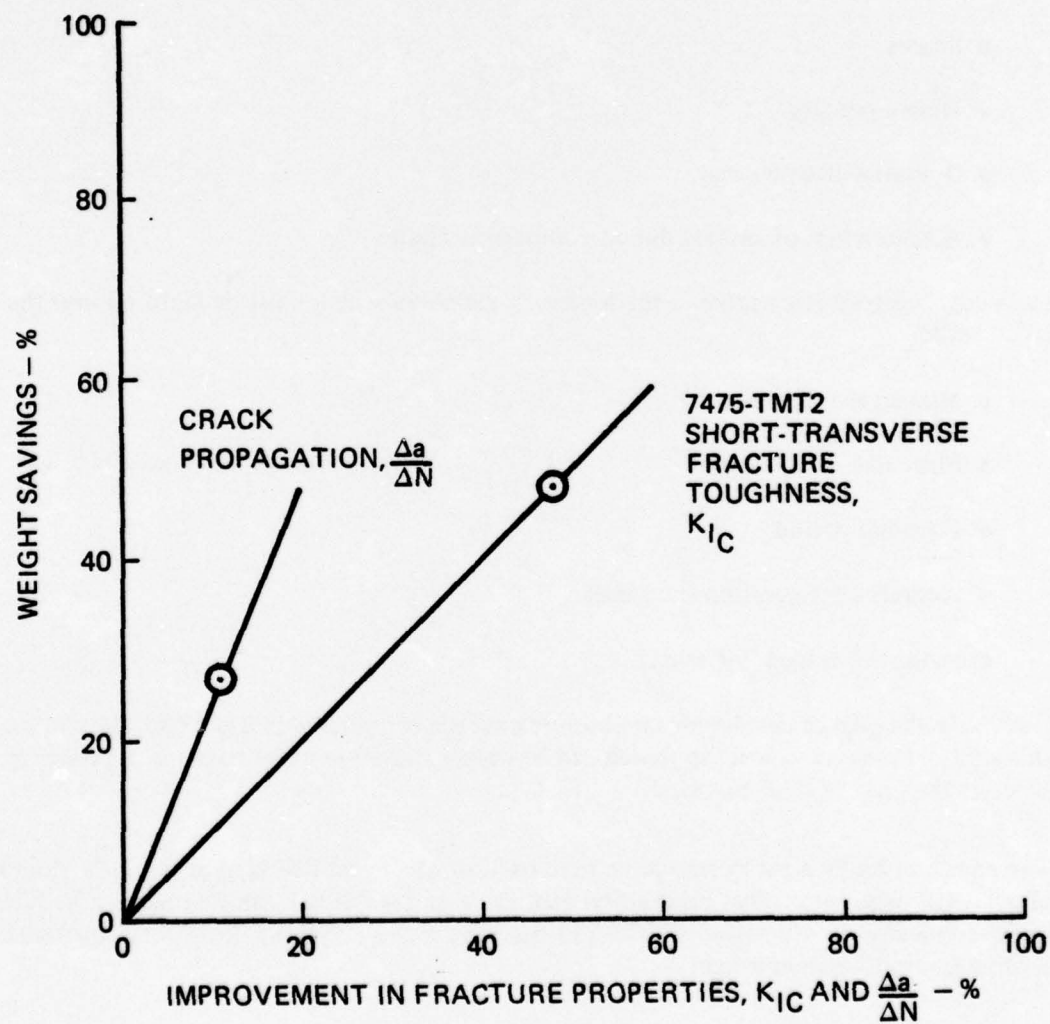


Figure 156. Weight Savings Available Through Improved Fracture Properties.

COST EFFECTIVENESS

Weight savings are potentially cost-effective. A cost analysis involves many factors which can be grouped in the following categories:

- Unit investment
- Support (maintenance, equipment, training)
- Spares
- Weight penalty
- Operated effectiveness
- Attrition loss of aircraft due to component failure

Each cost category is sensitive to the following variables, which must be factored into the true cost profile:

- Mission requirements
- Fleet size
- Fleet life period
- Aircraft configuration (i.e., size)
- Projected dollars (inflation)

Obviously the goal of developing an absolute cost is a formidable task beyond the scope of this study. However, a basic approach can be demonstrated in order to place in proper perspective the relative costs involved.

The equation for flyaway costs can be used to illustrate a cost saving by using TMT aluminum alloys. The assumption that production quantities of TMT aluminum forgings can be fabricated as economically as conventional 7075-T73 has been made. Flyaway costs of the airframe are estimated by subsystem weight.

Average airframe per unit cost of one production aircraft

$$= \sum_{i=1}^{19} \text{CAFFCA (i)} \quad (I)$$

and

$$\text{CAFFCA}(i) = \text{CAFFCL}(i) + \text{CAFFCM}(i) \quad (2)$$

$$\text{CAFFCL}(i) = \frac{A_{12L}(i) S(i) B_{12L}(i)}{NPAC} \times G^{12} \quad (3)$$

$$\text{CAFFCM}(i) = \frac{A_{12M}(i) S(i) B_{12M}(i)}{NPAC} \times G^{12} \quad (4)$$

- where AVFCP = average flyaway cost of production aircraft
 CAFFCA(i) = average subsystem cost of production aircraft
 CAFFCL(i) = labor portion of the average subsystem cost of production aircraft
 CAFFCM(i) = material portion of the average subsystem cost of production aircraft
 S(i) = weight of subsystem times total aircraft produced = X(i) x (NPAC + NOP)
 NPAC = number of production aircraft (excluding prototypes)
 G¹² = gross modifier of the airframe portion of flyaway
 NOP = number of prototypes.

The current baseline coefficients, B_{12L}(i) and B_{12M}(i), are given in Table 34. As an example, the production-aircraft cost savings will be demonstrated for a weight savings in the rotor system, subsystem 12. Since relative savings are of interest, it is possible to compare the flyaway cost equations for 7075-T73 and for 7475-TMT.

For a 5-percent weight saving in the rotor subsystem,

$$S(12)_{7475-TMT} = 0.95 S(12)_{7075-T73} \quad (5)$$

By substitution in equation 4,

$$\text{CAFFCM}(12)_{7075-T73} = \{A_{12M}(12)\} \left(\frac{G^{12}}{NPAC} \right) S(12)_{7075-T73} \frac{B_{12M}(12)}{7075-T73} \quad (6)$$

and

$$\text{CAFFCM}(12)_{7475-TMT} = \{A_{12M}(12)\} \left(\frac{G^{12}}{NPAC} \right) S(12)_{7475-TMT} \frac{B_{12M}(12)}{7475-TMT} \quad (7)$$

The relative cost savings can be determined by dividing equation 7 by equation 6 and substituting equation 5:

$$\begin{aligned}
 \text{CAFFCM}(12)_{7475\text{-TMT}} &= \text{CAFFCM}(12)_{7075\text{-T73}} \left(\frac{S(12)_{\text{TMT}}}{S(12)_{\text{T73}}} \right)^{B12M(12)} \\
 &= \text{CAFFCM}(12)_{7075\text{-T73}} \left(\frac{0.95}{1.00} \right)^{0.84899} \\
 &= 0.96 \text{ CAFFCM}(12)_{7075\text{-T73}},
 \end{aligned}$$

or a 4-percent savings in the flyaway cost of each production aircraft.

TABLE 34. SUBSYSTEM COST-WEIGHT COEFFICIENTS

Subsystem	X(i)	A12L(i)	B12L(i)	A12M(i)	B12M(i)
Fuselage	1	39,063.35	0.486394	126.88	0.812642
Wings	2	15,401.34	0.531771	98.45	0.809710
Nacelles	3	6,425.37	0.633160	484.84	0.846940
Empennage	4	24,383.69	0.468590	110.11	0.816530
Armor Plate	5	0.0	1.0	10.065	0.94226
Lighting Gear	6	1,953.87	0.623630	100.71	0.859430
Flight Controls	7	708.67	0.722290	255.48	0.854320
Hydraulic/Electrical	8	11,057.01	0.630270	613.32	0.865070
Instruments	9	1,914.29	0.697960	356.94	0.922710
Air Cond & Deicing	10	0	1.0	789.3	0.8635779
Personal Accom	11	0	1.0	35.935	0.8615416
Rotor System	12	2,889.21	0.646230	190.92	0.848990
Drive System	13	2,542.42	0.654770	267.82	0.847810
Fuel System	14	1,231.99	0.632870	312.42	0.857300
Engine Accessories	15	0	1.0	790.62	0.8550757
Airframe Electronics	16	0	1.0	1,391.2	0.8623805
Passenger/Cargo	17	0	1.0	69.647	0.8655591
Propeller Inst	18	2,889.21	0.646230	190.92	0.848990
Integration	19	54,852.0	0.4416448	0.0	1.0

CONCLUSIONS

The goal of this program was to achieve ITMT aluminum-alloy forgings that have equivalent tensile properties and stress corrosion resistance, and 20 percent better toughness fatigue properties than conventional 7075-T73 forgings. This goal has been achieved and, in some instances, exceeded:

1. Tensile properties of ITMT aluminum-alloy forgings are better than those of 7075-T73 forgings in that the TMT materials have equivalent strength, higher elongation, and reduction in area.
2. Fracture-toughness values of ITMT aluminum-alloy forgings are as much as 62 percent higher than conventional 7075-T73 forgings.
3. Fatigue properties of ITMT aluminum-alloy forgings are as much as 62 percent higher than conventional 7075-T73 forging properties.
4. Stress-corrosion properties of TMT aluminum-alloy forgings are equivalent to 7075-T73 forging properties.

These advantages have been achieved within the limits of current industrial forging practices. Undoubtedly, the potential for still further improvements exists if present-day forging constraints imposed by machine capacity are expanded beyond today's industrial limits. It has been demonstrated that ITMT forgings are cost-effective. The development of further improvements in ITMT forging technology will, therefore, also improve the cost-effectiveness of these practices.

RECOMMENDATIONS

The results of this program show that Intermediate Thermal-Mechanical Treatment (ITMT) is a technique for improving the properties of 7XXX-series aluminum-alloy forgings, and that it is a cost-effective means of saving weight in helicopter components. The next step recommended is a program for the fabrication of an actual helicopter component using an ITMT-processed aluminum alloy and for side-by-side test evaluation of this component with a conventional aluminum component.

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2. Sommer, A. W., Paton, N. E., and Folgner, D. G., EFFECTS OF THERMOMECHANICAL TREATMENTS ON ALUMINUM ALLOYS, AFML-TR-72-5, February 1972.
3. Thompson, D. S., Levy, S. A., Spangler, G. E., and Benson, D. K., PROGRAM TO IMPROVE THE FRACTURE TOUGHNESS AND FATIGUE RESISTANCE OF ALUMINUM SHEET AND PLATE FOR AIRCRAFT APPLICATIONS, WPAFB Contract F33615-72-C-1202, Semiannual report for the period June 1, 1972, to December 31, 1972, January 1973.
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5. Ostermann, F., IMPROVED FATIGUE RESISTANCE OF Al-Zn-Mg-Cu (7075) ALLOYS THROUGH THERMOMECHANICAL PROCESSING, *Metallurgical Transactions*, 2, 2897-2902, 1971.
6. Ruch, L., and Sulinski, H., FINAL THERMAL MECHANICAL TREATMENT OF 7039, 7075, X7007, AND X7050 ALLOYS, Frankford Arsenal report (in preparation).
7. Hyatt, M. V., Early, D. O., and Pasley, D. H., PROGRAM TO IMPROVE THE FRACTURE TOUGHNESS AND FATIGUE RESISTANCE OF ALUMINUM SHEET AND PLATE FOR AIRFRAME APPLICATIONS, WPAFB Contract No. F33615-72-C-1649, Semiannual report for period July 1, 1972, to December 31, 1972, January 1973.
8. Waldman, J., Sulinski, H., and Markus, H., NEW PROCESSING TECHNIQUES FOR ALUMINUM ALLOYS, presented at the Army Materials Technology Conference on Solidification Technology, Wentworth by the Sea, New Hampshire, October 1972.
9. STANDARD TENSION TEST, E8-61T, American Society for Testing and Materials, Philadelphia, Pennsylvania.
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Boyd, J. D., Drennan, D. C., Martin, C. J., Price, C. W., Rosenfield, A. R., and Williams, D. N., RESEARCH ON SYNTHESIS OF HIGH STRENGTH ALUMINUM ALLOYS, Technical Report AFML-TR-72-199, July 1, 1971 to July 31, 1972.

1964 BOOK OF ASTM STANDARDS, PART 30, GENERAL TESTING METHODS; QUALITY CONTROL; APPEARANCE TESTS; TEMPERATURE MEASUREMENT; EFFECT OF TEMPERATURE, American Society for Testing and Materials, Philadelphia, Pennsylvania.

APPENDIX A

LOCATION AND ORIENTATION OF TEST SPECIMENS IN TASK II FORGINGS

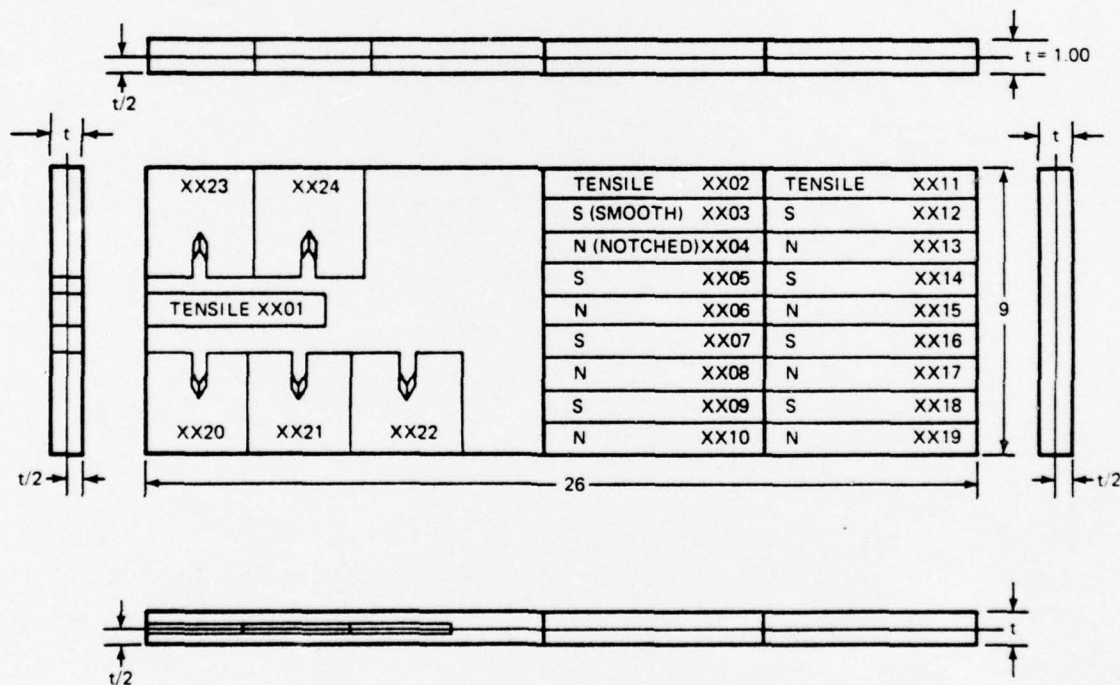
Figures A1, A2, and A3 indicate forging dimensions and define the sequence of events for producing the final sections used to fabricate test specimens.

The exact location of each individual test specimen can be identified from Figures A4 through A7.

ALL DIMENSIONS ARE IN INCHES.

SPECIMEN TYPE	QUANTITY	NOMINAL DIMENSIONS FOR SPECIMEN BLANKS
TENSILE	3	5.7 x 1 x 1
FATIGUE	8 } 16	6.7 x 0.8 x 0.8
SMOOTH		6.7 x 0.8 x 0.8
NOTCHED	8 } 16	6.7 x 0.8 x 0.8
CRACK-PROPAGATION		3.2 x 3.2 x 0.6
FRACTURE-TOUGHNESS	2	3.5 x 3.4 x 1.0

MATERIAL	SECTION IDENTIFICATION NUMBER, XX
7075-T73	01
7475-TMT1	07
7475-TMT2	13



NOTE: $t/2$, THE CENTERLINE OF THE SECTION, SHALL CORRESPOND TO THE CENTERLINE OF ALL SPECIMENS AS SHOWN.

Figure A1. One-Inch-Thick Forging for Specimens XX01 Through XX24.

MATERIAL	SECTION IDENTIFICATION NUMBER, XX
7475 TMT1	08
7475 TMT2	14

NOTE: 1/2" THE CENTERLINE OF THE SECTION, SHALL CORRESPOND TO THE CENTERLINE OF ALL SPECIMENS AS SHOWN.

SPECIMEN TYPE	QUANTITY	NOMINAL DIMENSIONS FOR SPECIMEN BLANKS
TENSILE	3	5.7 x 1 x 1
FATIGUE	25	6.7 x 0.8 x 0.8
SMOOTH	24	6.7 x 0.8 x 0.8
NOTCHED	3	3.2 x 3.2 x 0.8
CRACK PROPAGATION	2	3.5 x 3.4 x 1.4
FRACTURE TOUGHNESS		

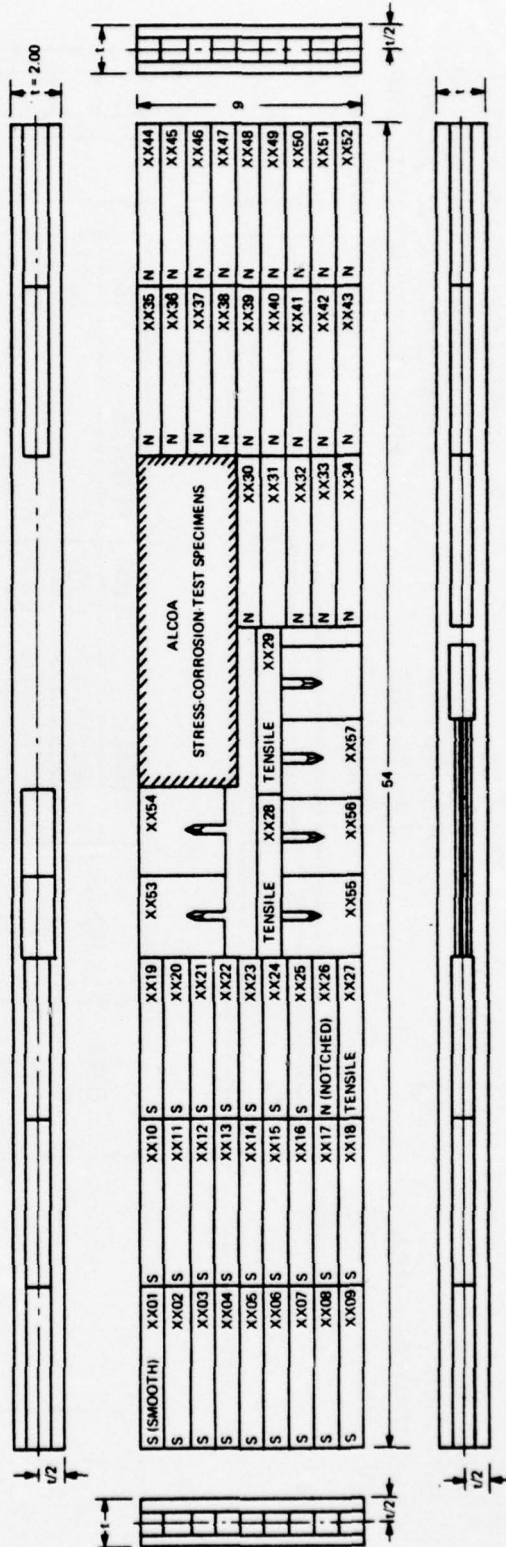


Figure A2. Two-Inch-Thick Forging for Specimens XX01 Through XX57.

NOTES:

1. $t/2$, THE CENTERLINE OF THE SECTION, SHALL CORRESPOND TO THE CENTERLINE OF ALL SPECIMENS AS SHOWN.
2. STRESS-CORROSION SPECIMENS FOR ALCOA WERE REMOVED FROM LEFT SIDE OF SECTION PRIOR TO DELIVERY TO THE BOEING VERTOL COMPANY.

ALL DIMENSIONS ARE IN INCHES.

NOMINAL DIMENSIONS
FOR SPECIMEN BLANKS

SPECIMEN TYPE	QUANTITY	NOMINAL DIMENSIONS FOR SPECIMEN BLANKS
TENSILE	3	5.7 x 1 x 1
FATIGUE		
SMOOTH	8	6.7 x 0.8 x 0.8
NOTCHED	8	6.7 x 0.8 x 0.8
CRACK-PROPAGATION	3	3.2 x 3.2 x 0.6
FRACTURE-TOUGHNESS	2	3.5 x 3.4 x 1.4

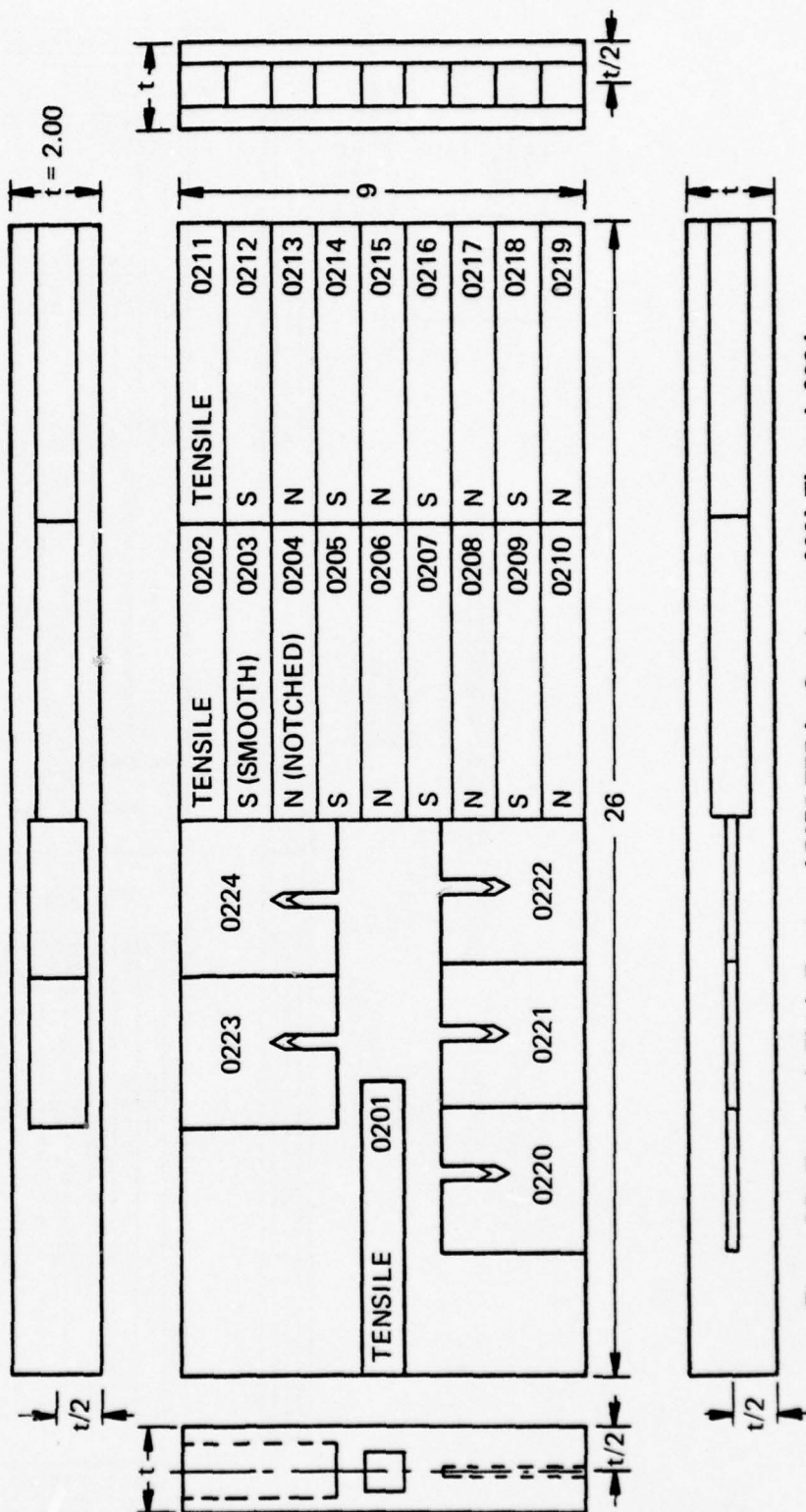
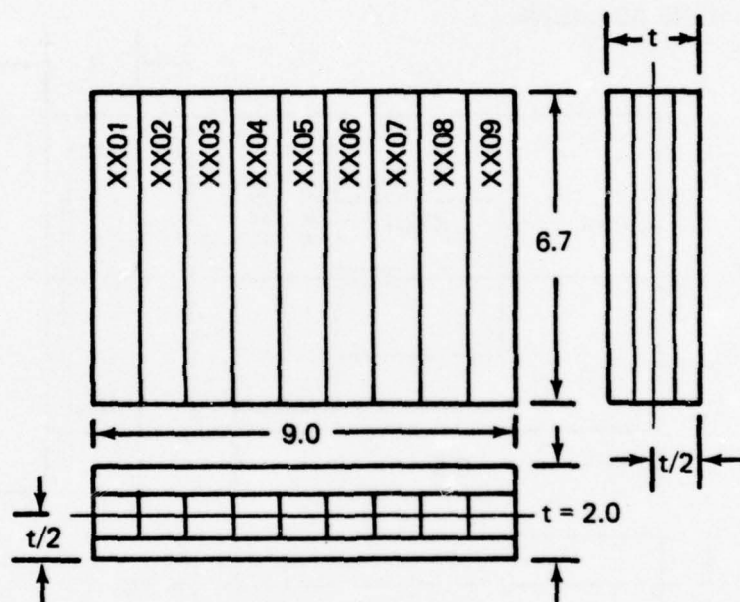


Figure A3. Two-Inch-Thick Forging of 7075-T73 for Specimens 0201 Through 0224.

<u>SPECIMEN TYPE</u>	<u>QUANTITY</u>	<u>NOMINAL DIMENSIONS FOR SPECIMEN BLANKS</u>
FATIGUE, SMOOTH	9	6.7 x 0.8 x 0.8

ALL DIMENSIONS ARE IN INCHES.



NOTE: $t/2$, THE CENTERLINE OF THE SECTION, SHALL CORRESPOND TO THE CENTERLINE OF ALL SPECIMENS AS SHOWN.

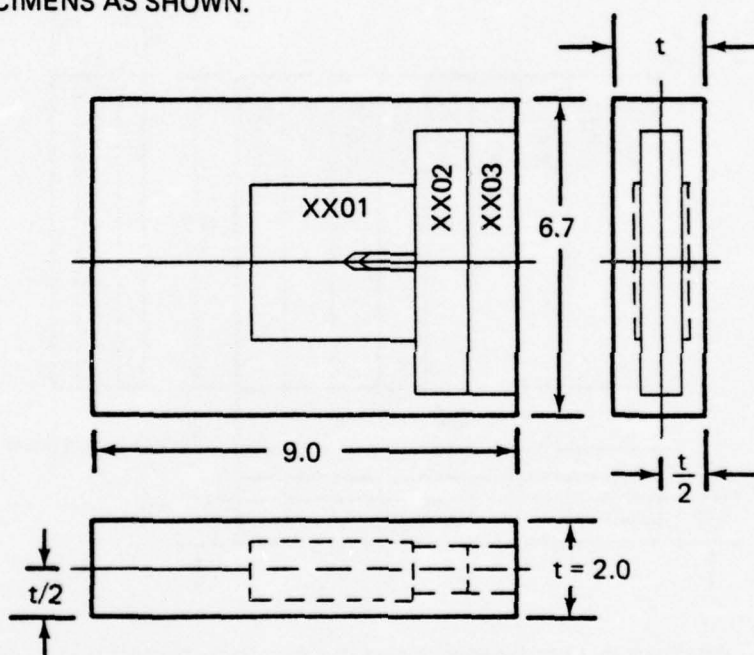
MATERIAL	SECTION IDENTIFICATION NUMBER, XX
7075-T73	03
7475-TMT1	09
7475-TMT2	15

Figure A4. 6.7-Inch-Thick Forging for Specimens XX01 Through XX08.

<u>SPECIMEN TYPE</u>	<u>QUANTITY</u>	<u>NOMINAL DIMENSIONS FOR SPECIMEN BLANKS</u>
TENSILE	2	5.7 x 1 x 1
FRACTURE-TOUGHNESS	1	3.5 x 3.4 x 1.4

NOTE: $t/2$, THE CENTERLINE OF THE SECTION, SHALL CORRESPOND TO THE CENTERLINE OF ALL SPECIMENS AS SHOWN.

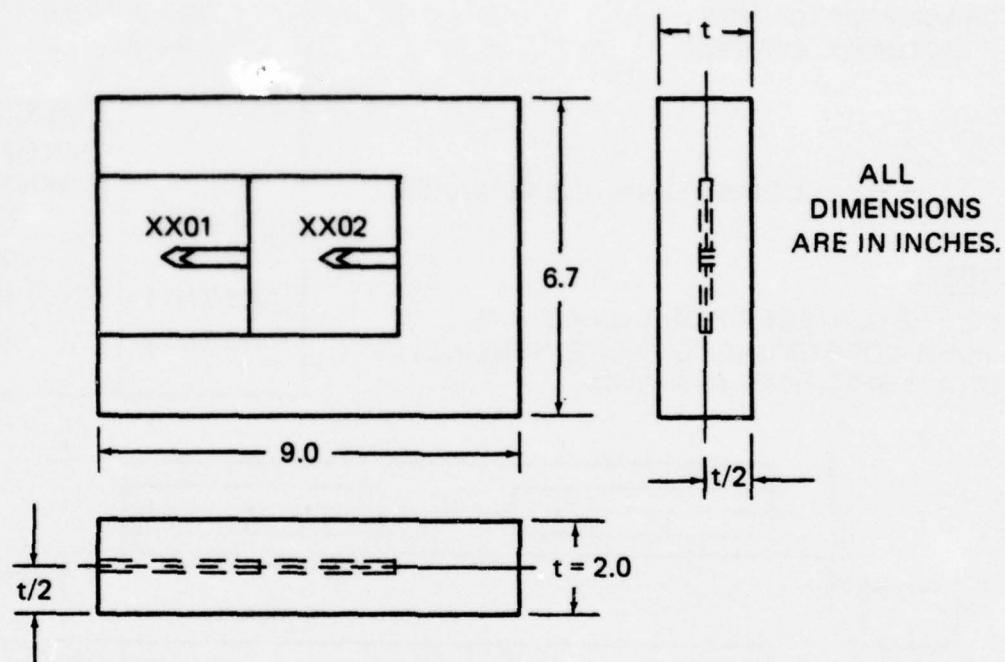
ALL DIMENSIONS ARE IN INCHES.



MATERIAL	SECTION IDENTIFICATION NUMBER, XX
7075-T73	04
7475-TMT1	10
7475-TMT2	16

Figure A5. 6.7-Inch-Thick Forging for Specimens XX01, XX02, and XX03.

<u>SPECIMEN TYPE</u>	<u>QUANTITY</u>	<u>NOMINAL DIMENSIONS FOR SPECIMEN BLANKS</u>
CRACK-PROPAGATION	2	3.2 x 3.2 x 0.6



NOTE: $t/2$, THE CENTERLINE OF THE SECTION, SHALL CORRESPOND TO THE CENTERLINE OF ALL SPECIMENS AS SHOWN.

MATERIAL	SECTION IDENTIFICATION NUMBER, XX
7075-T73	05
7475-TMT1	11
7475-TMT2	17

Figure A6. 6.7-Inch-Thick Forging for Specimens XX01 and XX02.

<u>SPECIMEN TYPE</u>	<u>QUANTITY</u>	<u>NOMINAL DIMENSIONS FOR SPECIMEN BLANKS</u>
TENSILE	2	5.7 x 1 x 1
FATIGUE, SMOOTH	8	6.7 x 0.8 x 0.8
CRACK-PROPAGATION	2	3.2 x 3.2 x 0.6
FRACTURE-TOUGHNESS	1	3.5 x 3.4 x 1.4

ALL DIMENSIONS ARE IN INCHES.

NOTE:

t/2, THE CENTERLINE OF THE SECTION, SHALL CORRESPOND TO THE CENTERLINE OF ALL SPECIMENS AS SHOWN.

<u>MATERIAL</u>	<u>SECTION IDENTIFICATION NUMBER, XX</u>
7075-T73	06
7475-TMT1	12
7475-TMT2	18

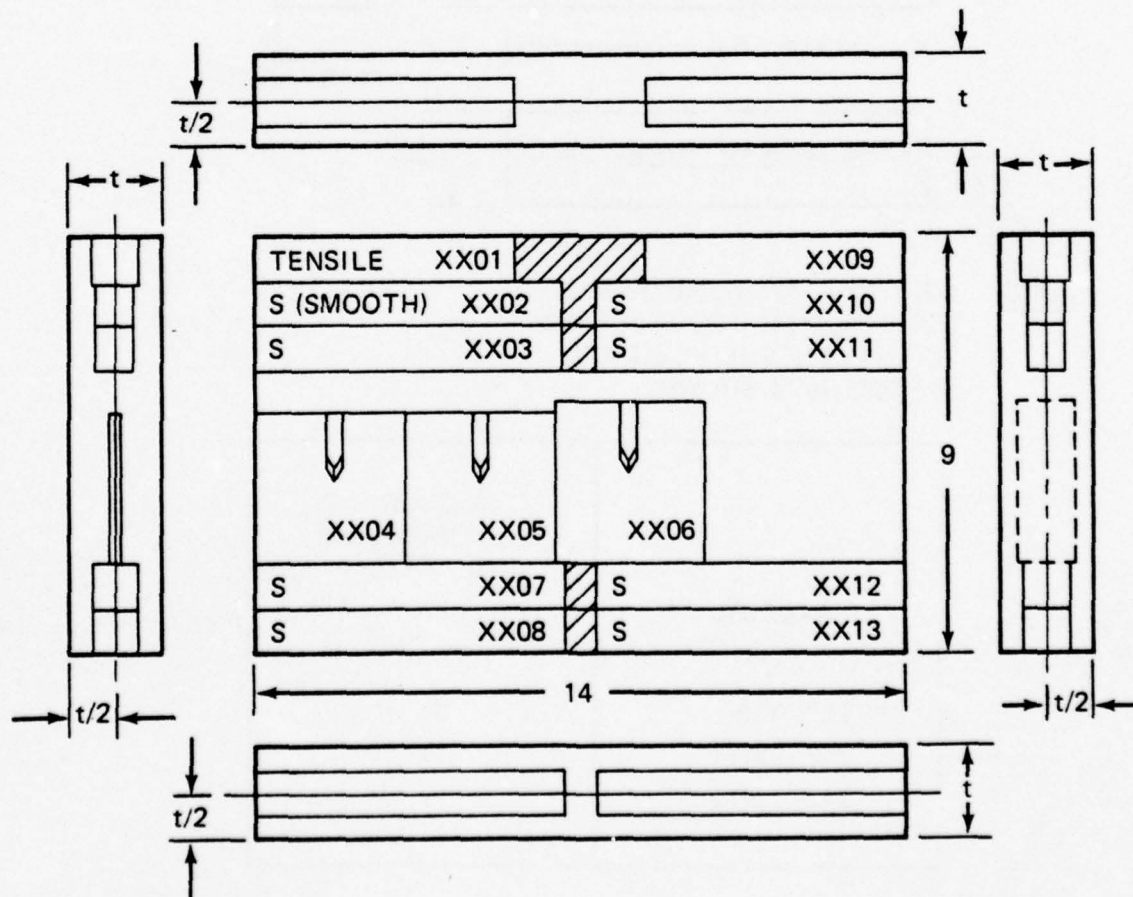


Figure A7. 6.7-Inch-Thick Forging for Specimens XX01 Through XX13.

APPENDIX B

LOAD-STRAIN PLOTS OF FORGING SPECIMENS

Load-strain traces for the 30 standard tension tests
are presented in Figures B1 through B12.

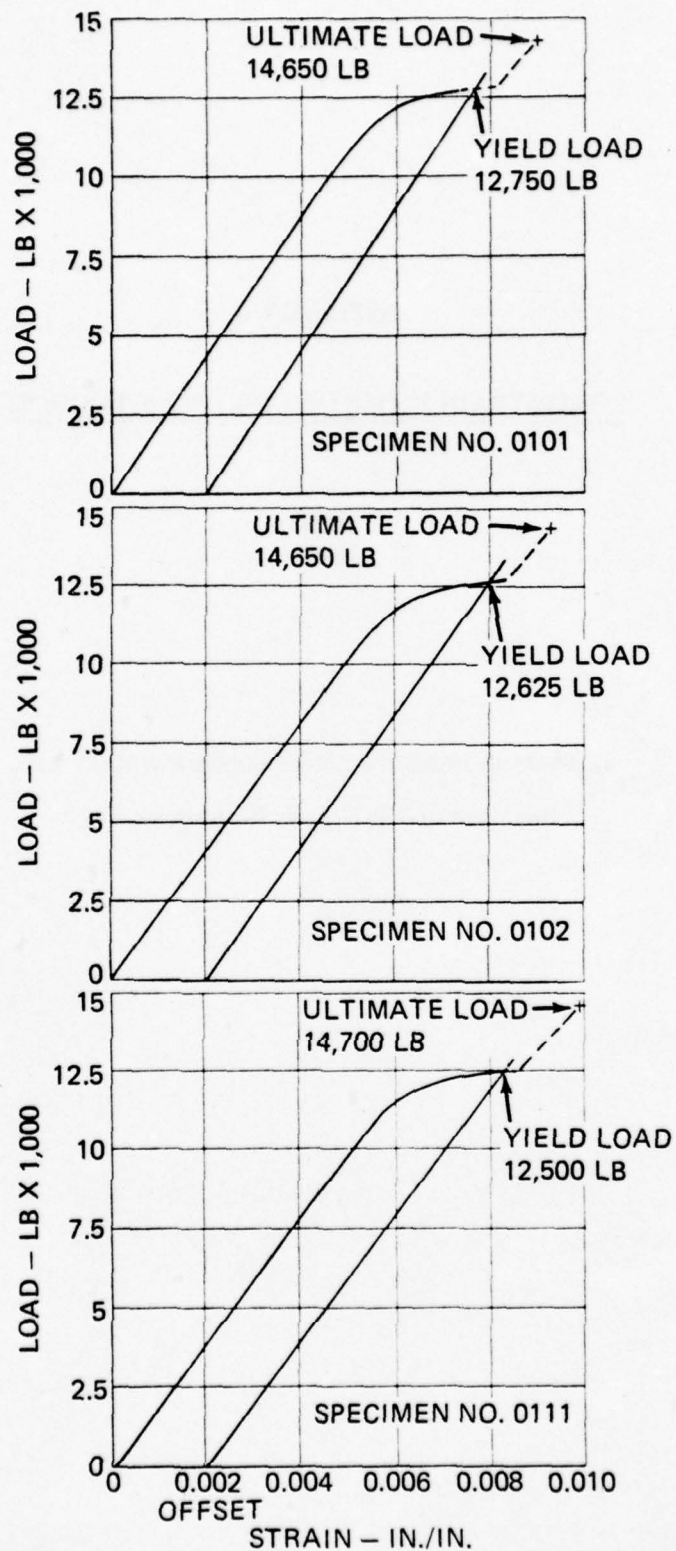


Figure B1. Tension Tests of Standard Round Specimens No. 0101, 0102, and 0111.

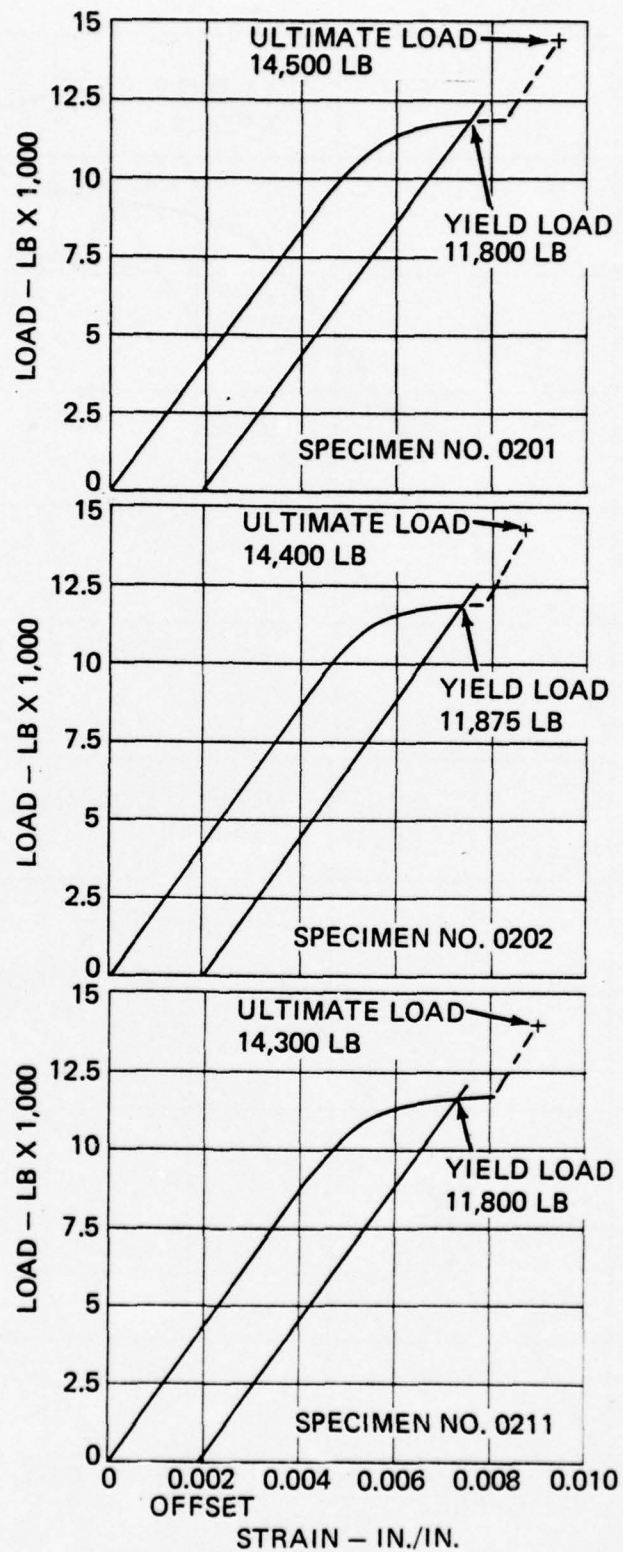


Figure B2. Tension Tests of Standard Round Specimens No. 0201, 0202, and 0211.

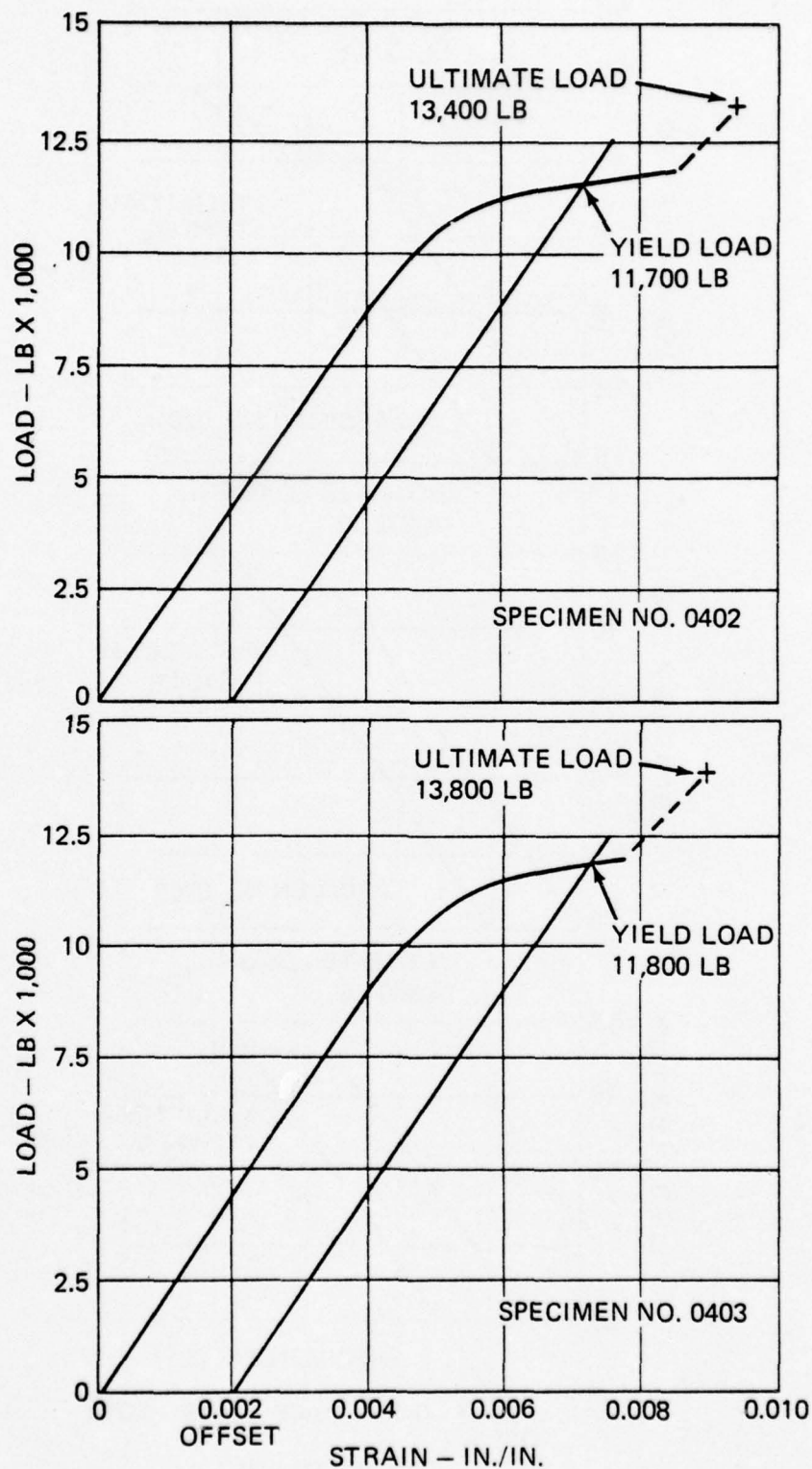


Figure B3. Tension Tests of Standard Round Specimens No. 0402 and 0403.

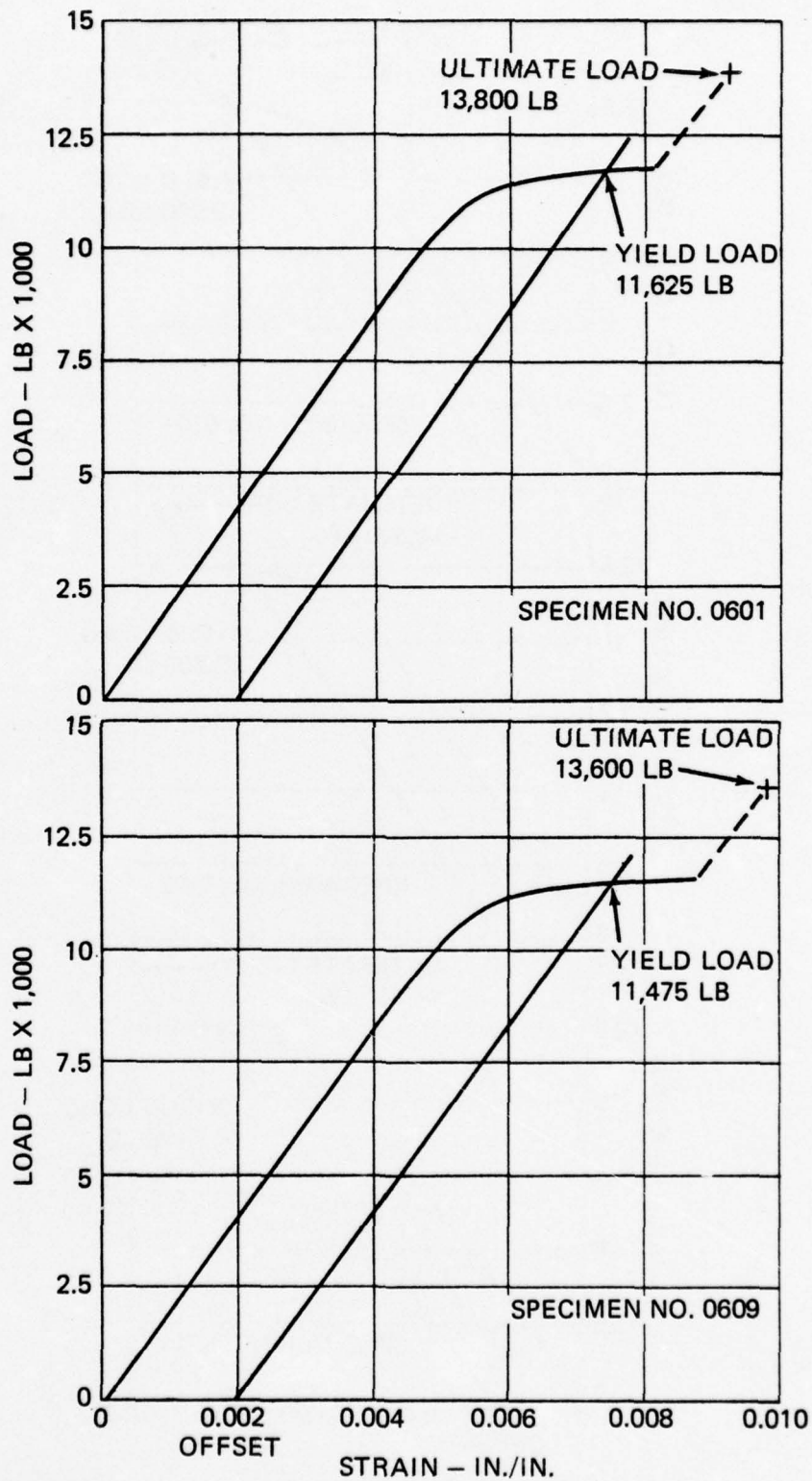


Figure B4. Tension Tests of Standard Round Specimens No. 0601 and 0609.

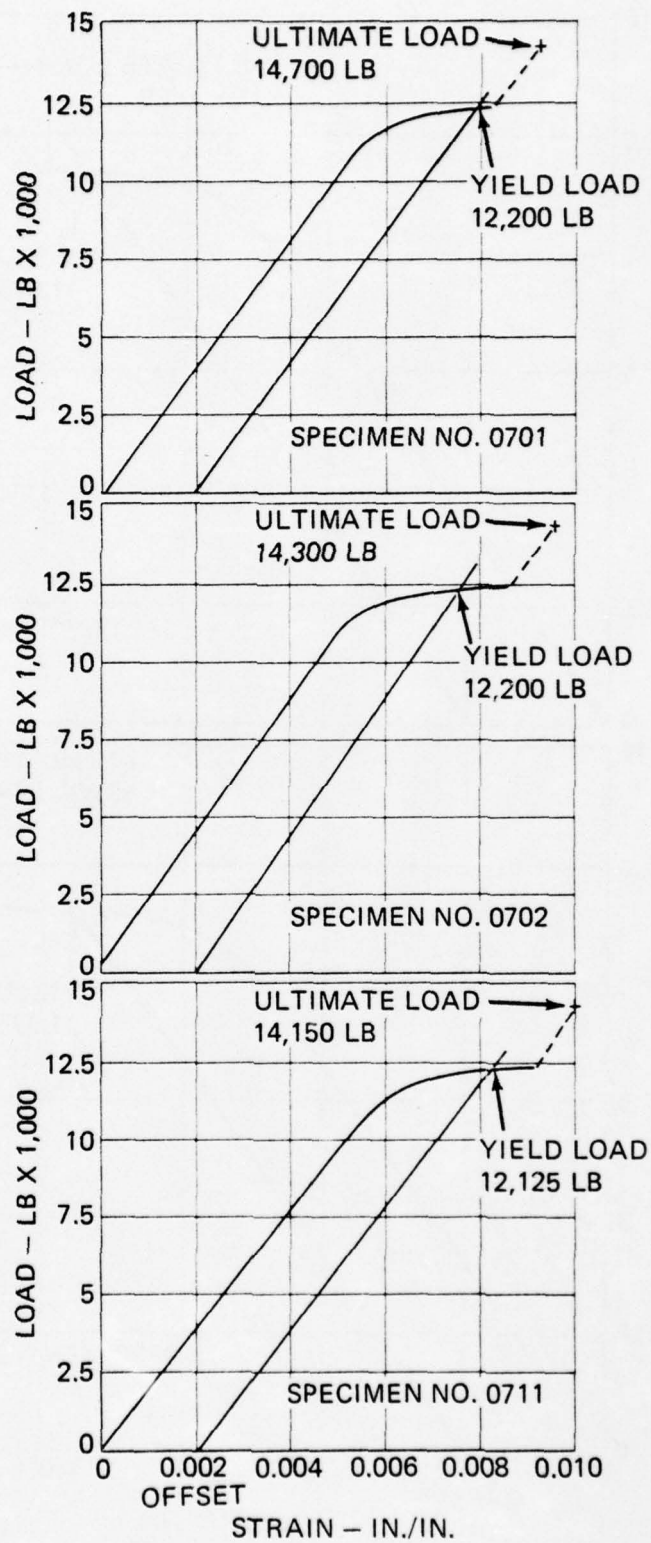


Figure B5. Tension Tests of Standard Round Specimens No. 0701, 0702, and 0711.

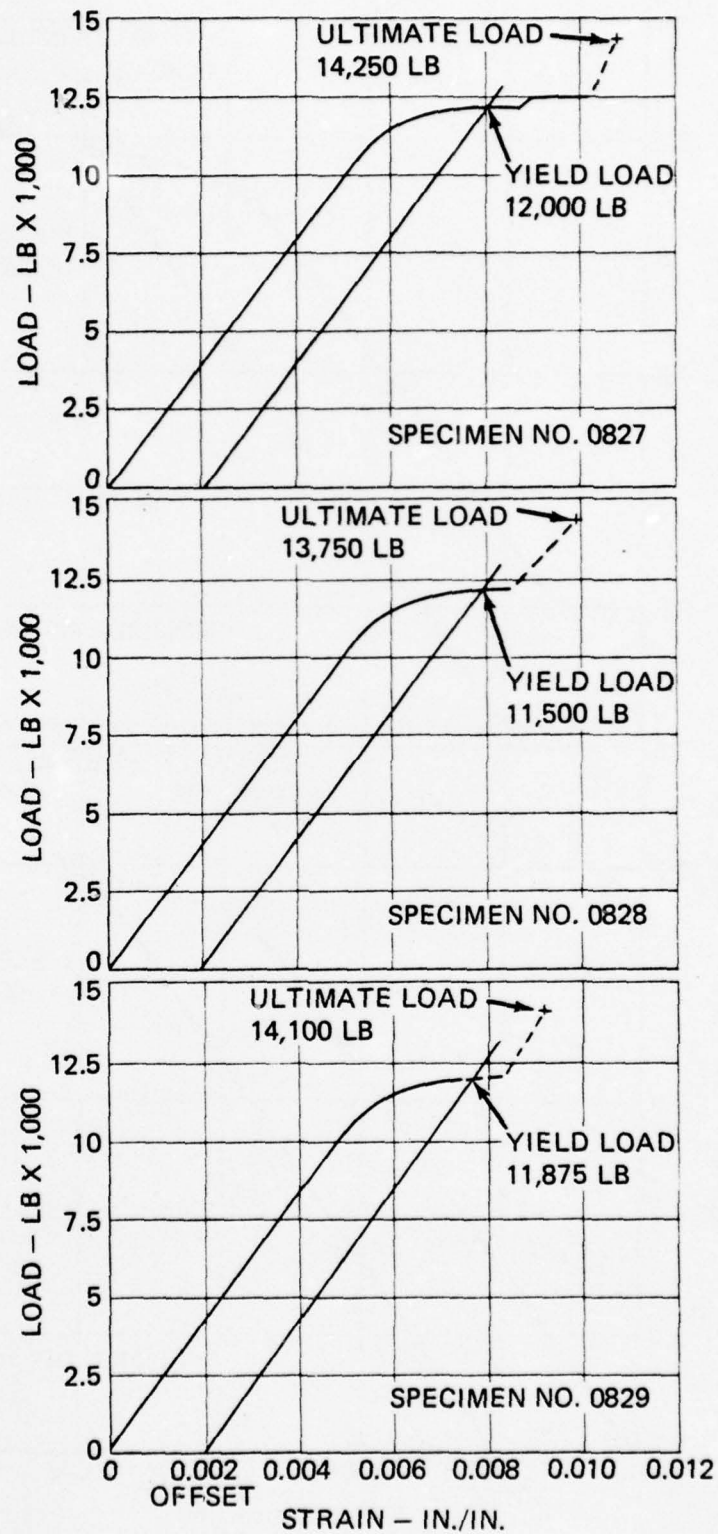


Figure B6. Tension Tests of Standard Round Specimens No. 0827, 0828, and 0829.

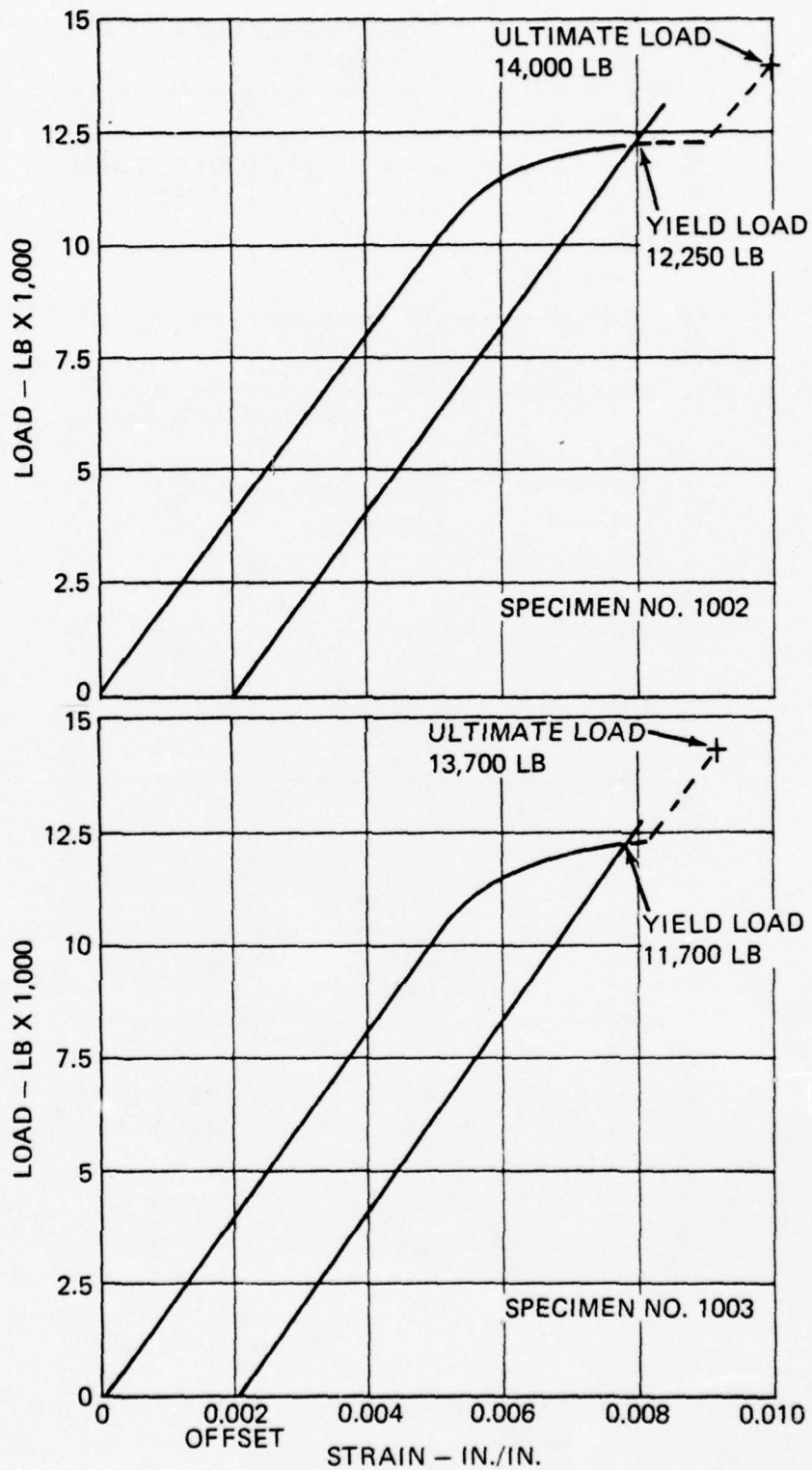


Figure B7. Tension Tests of Standard Round Specimens No. 1002 and 1003.

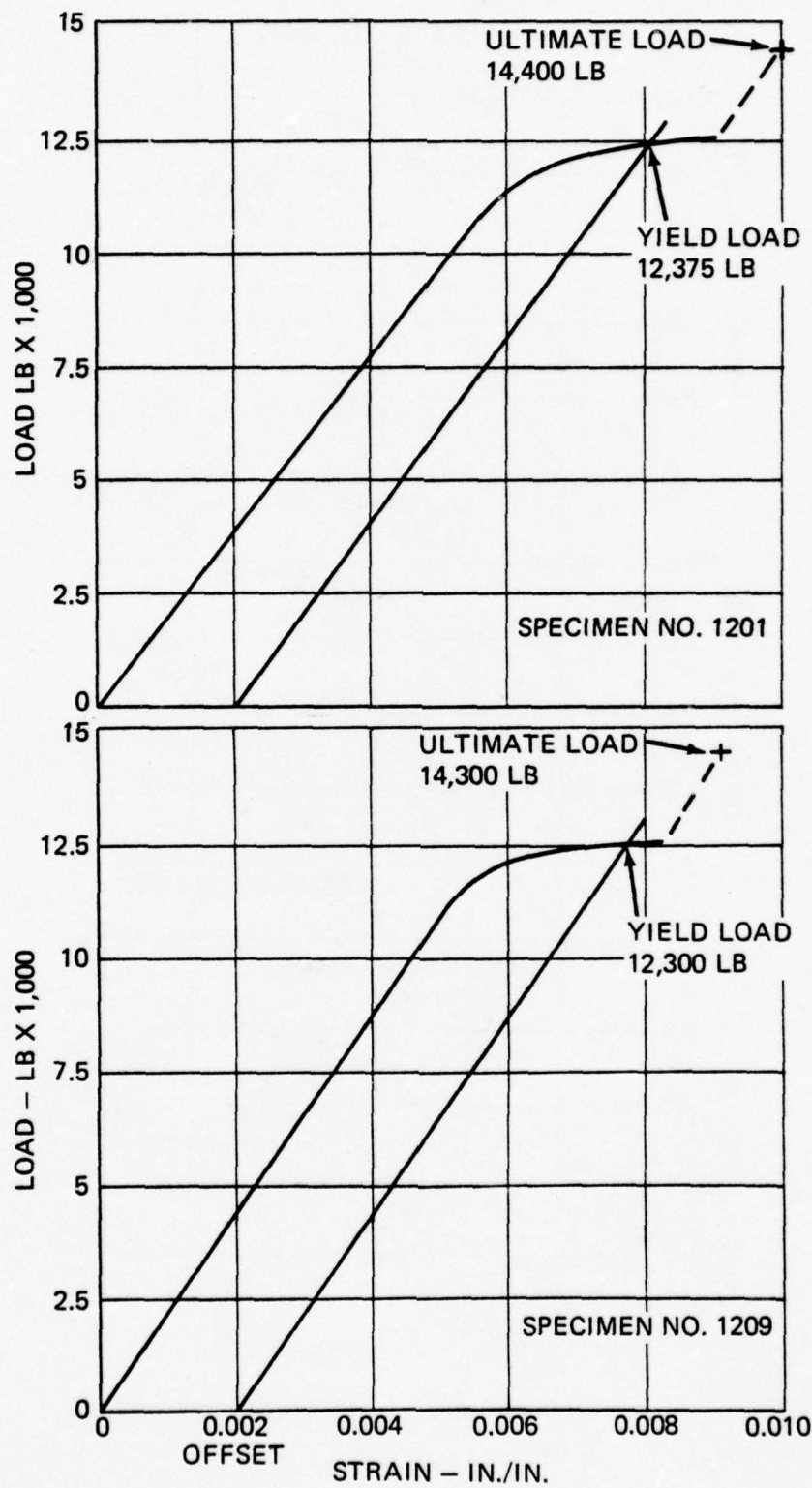


Figure B8. Tension Tests of Standard Round Specimens No. 1201 and 1209.

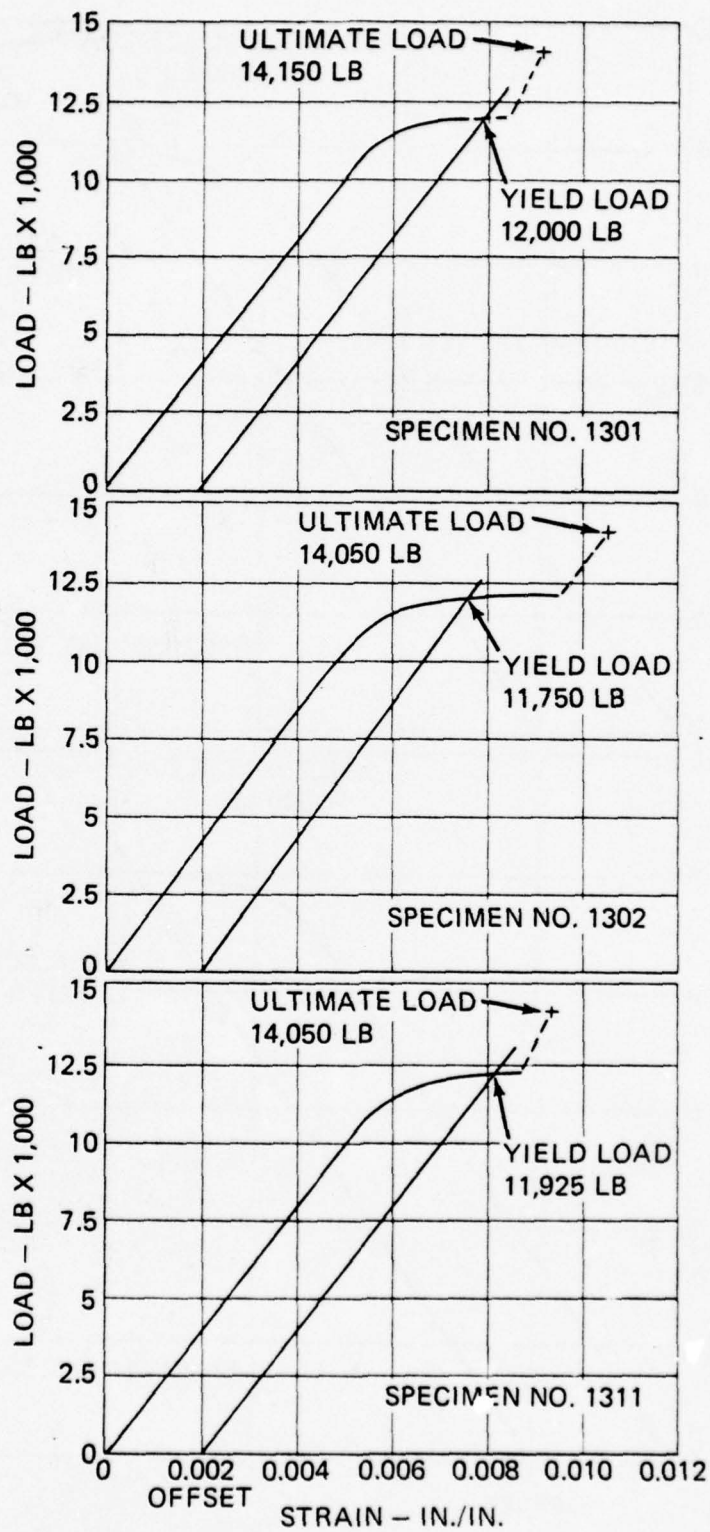


Figure B9. Tension Tests of Standard Round Specimens No. 1301, 1302, and 1311.

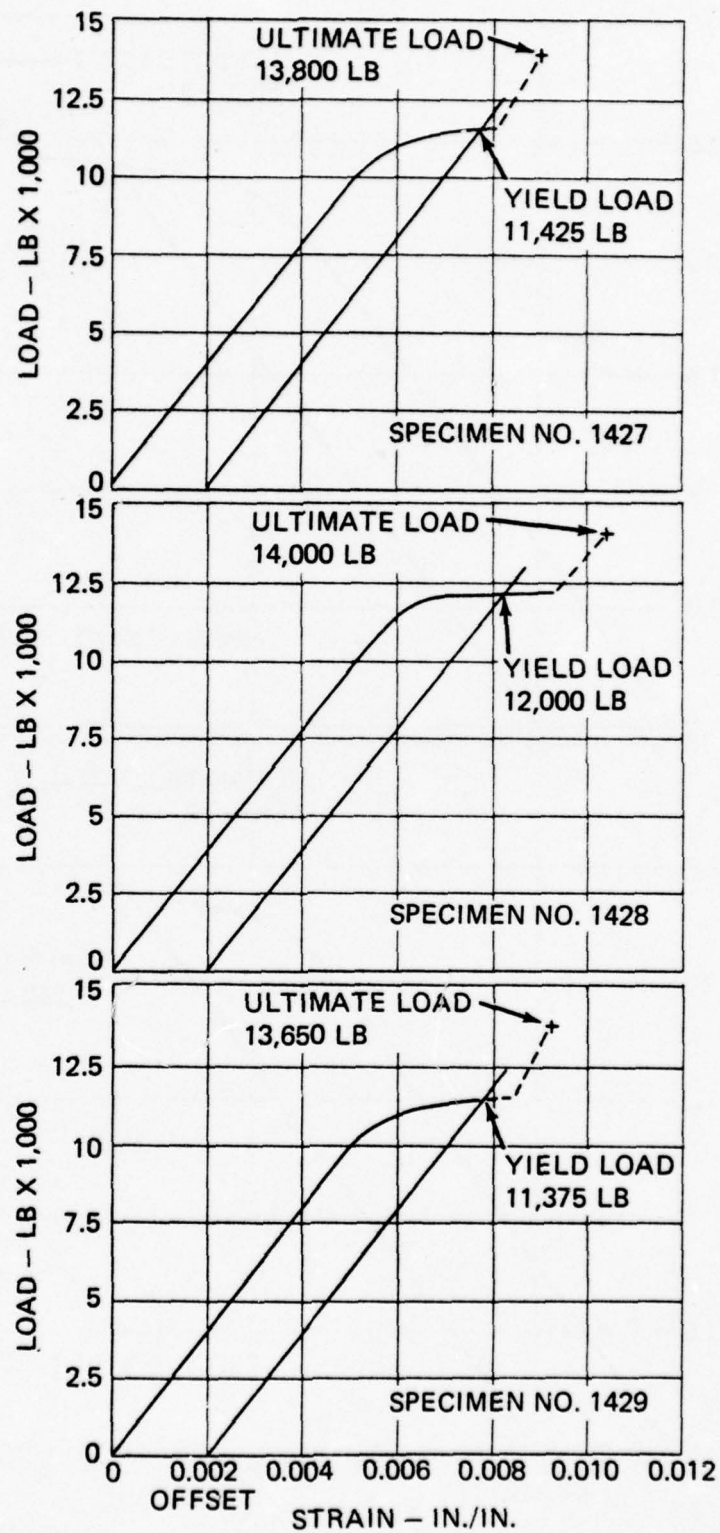


Figure B10. Tension Tests of Standard Round Specimens No. 1427, 1428, and 1429.

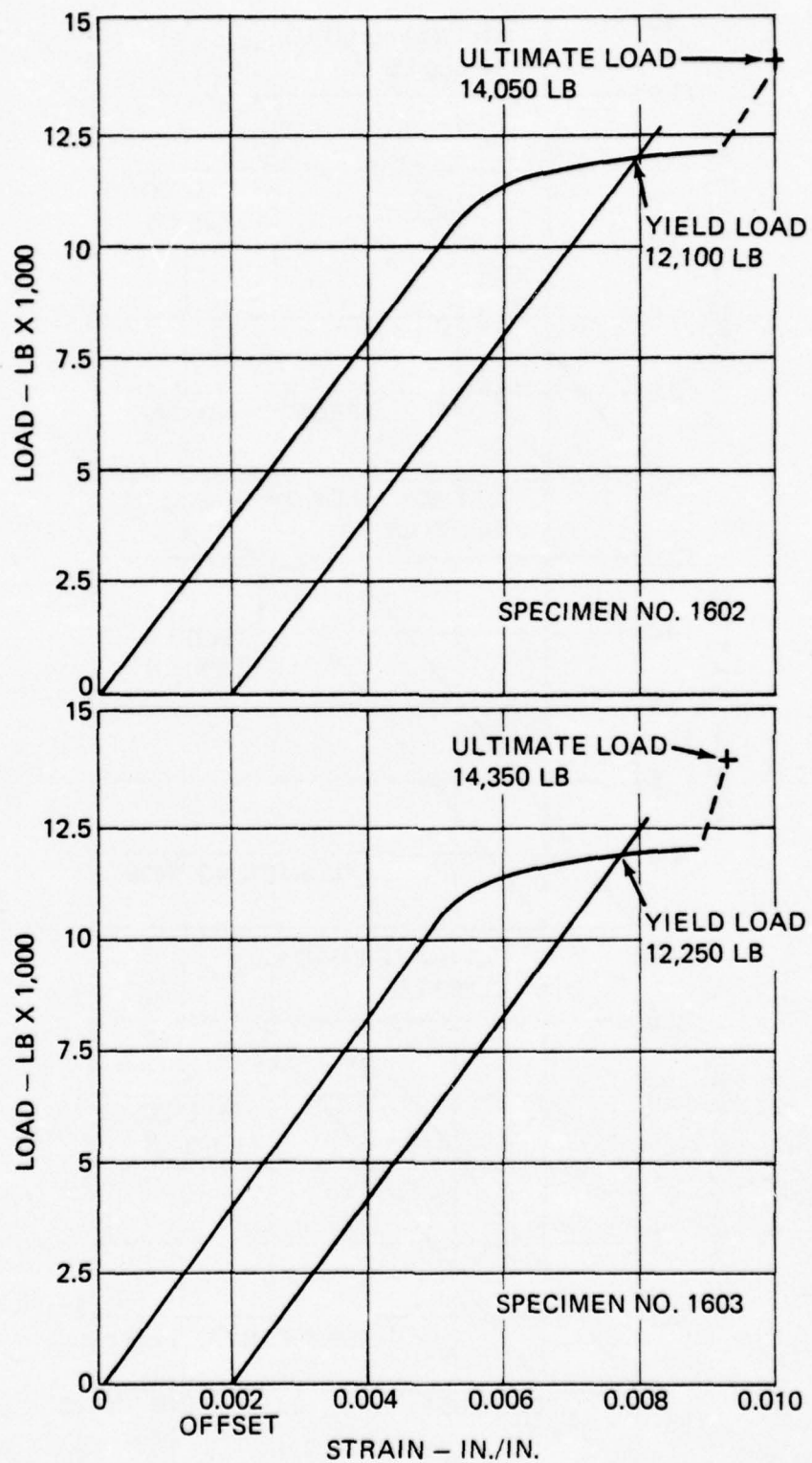


Figure B11. Tension Tests of Standard Round Specimens No. 1602 and 1603.

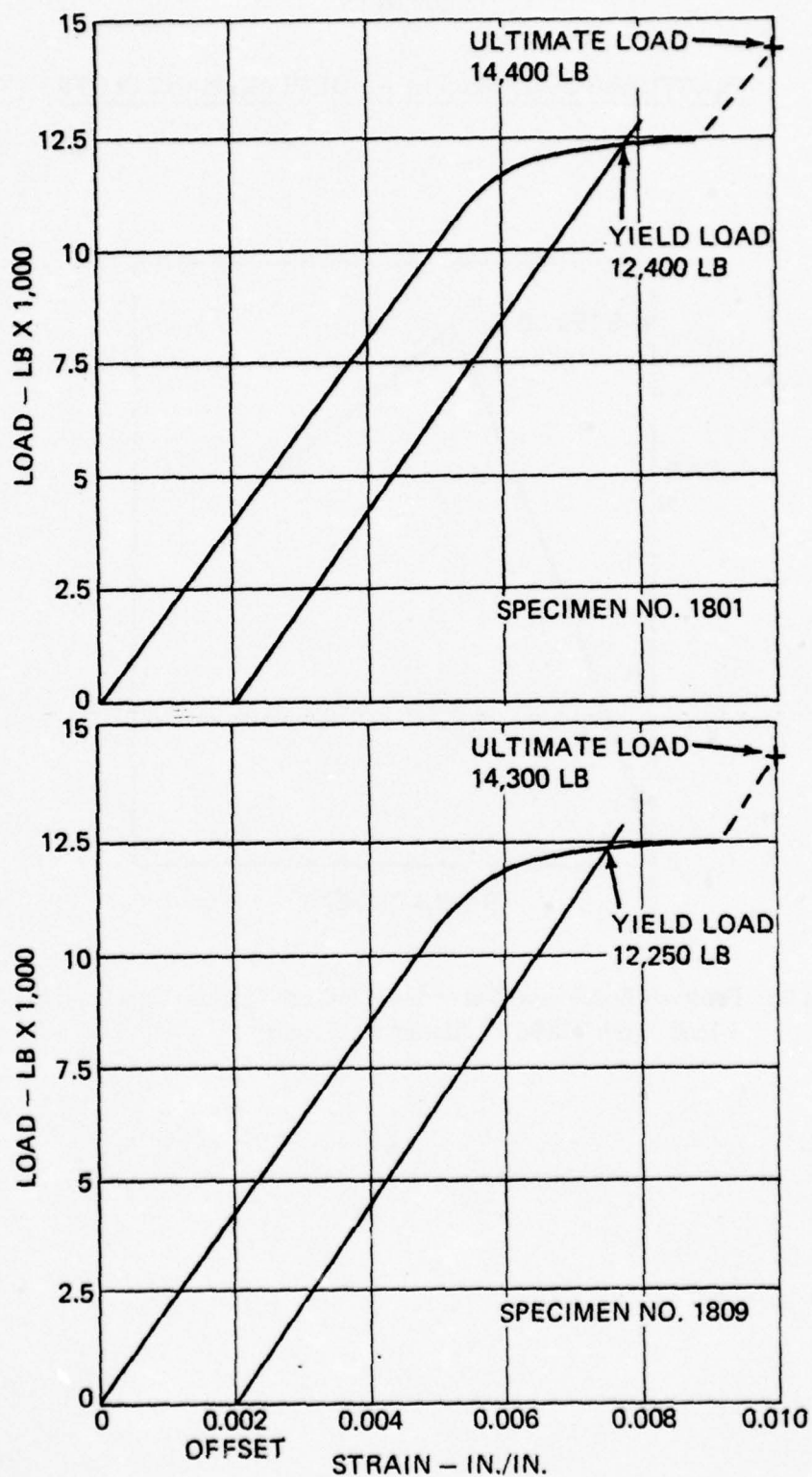


Figure B12. Tension Tests of Standard Round Specimens No. 1801 and 1809.

APPENDIX C

FRACTURE-TOUGHNESS LOAD-DISPLACEMENT PLOTS

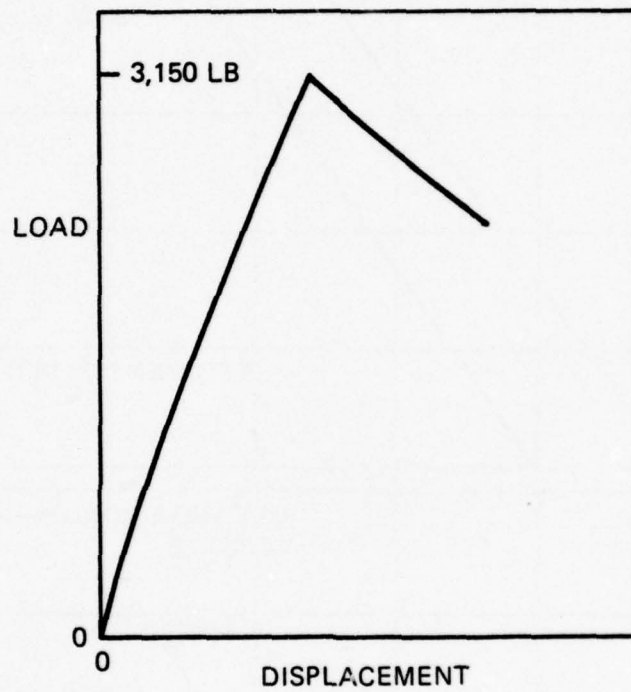


Figure C1. Fracture-Toughness Test of Longitudinal-Compact Specimen No. 0124, 1-Inch Thick 7075-T73 Aluminum Forging.

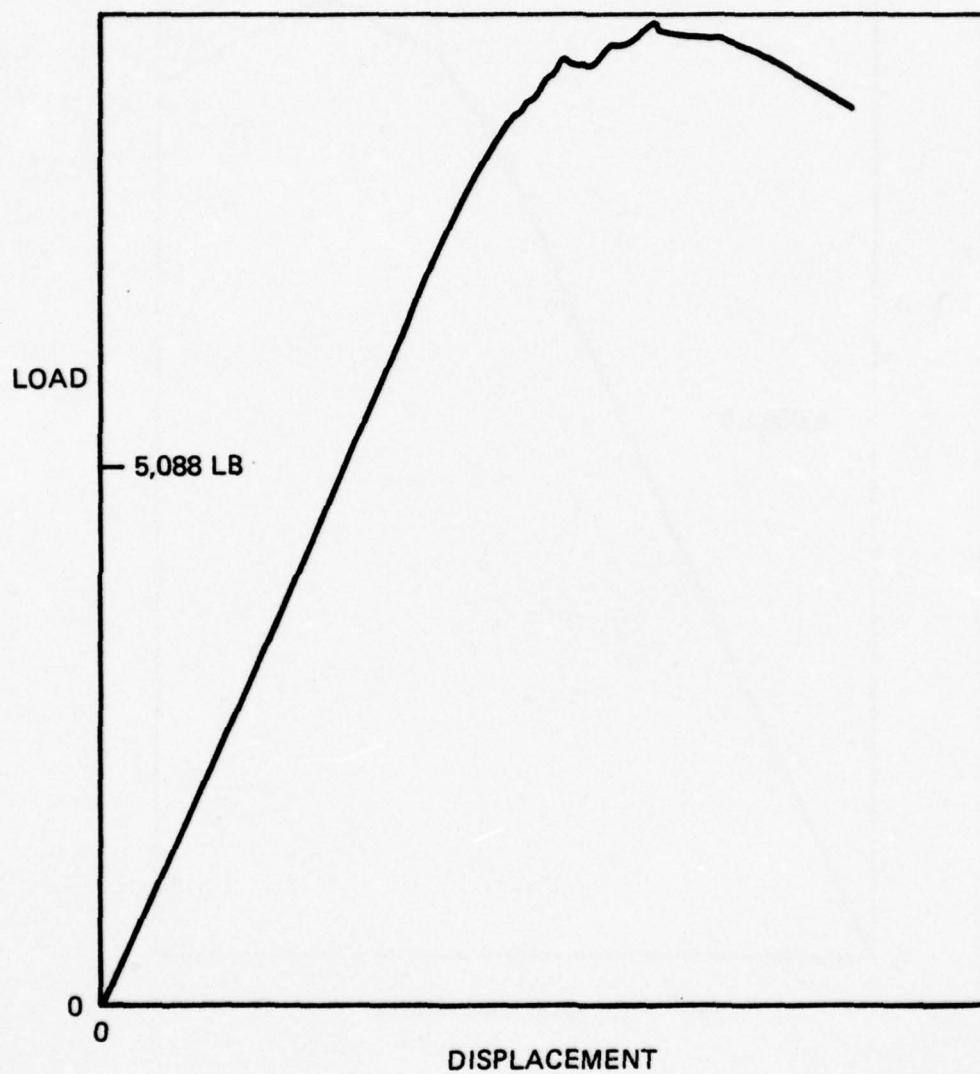


Figure C2. Fracture-Toughness Test of Longitudinal-Compact Specimen No. 0223, 2-Inch Thick 7075-T73 Aluminum Forging.

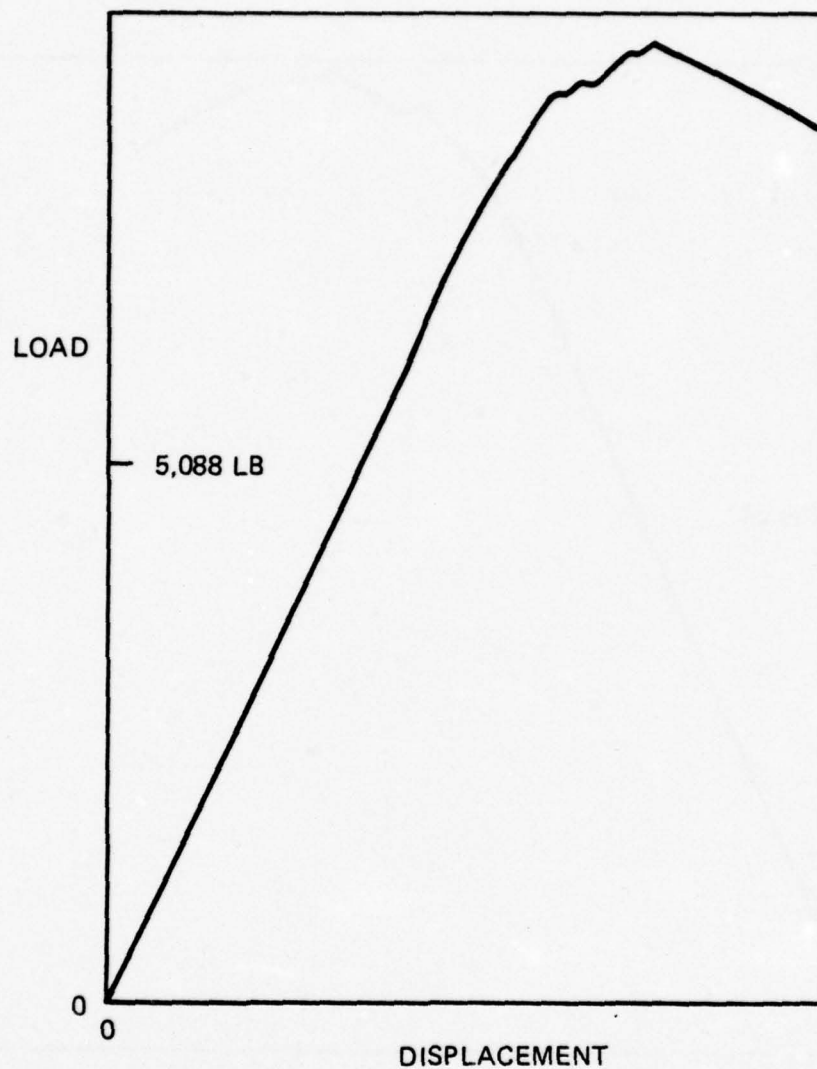


Figure C3. Fracture-Toughness Test of Longitudinal-Compact Specimen No. 0224, 2-Inch-Thick 7075-T73 Aluminum Forging.

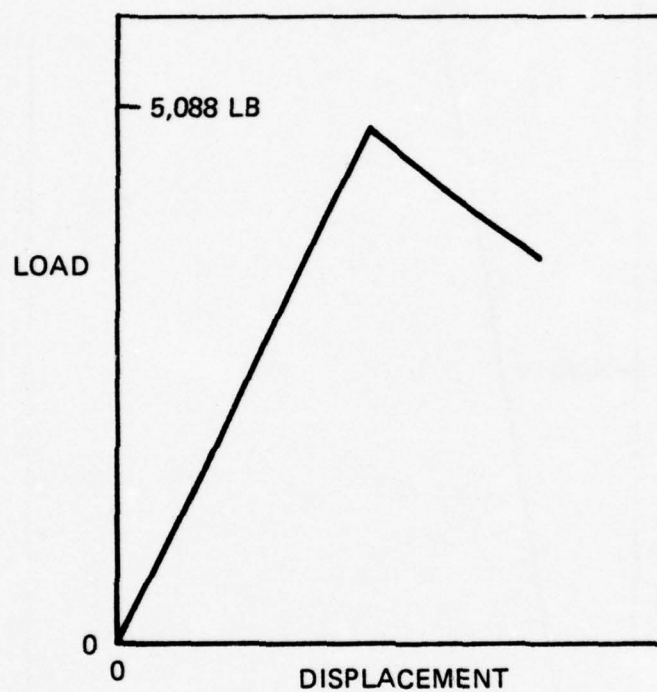


Figure C4. Fracture-Toughness Test of Short-Transverse-Compact Specimen No. 0401, 6.7-Inch-Thick 7075-T73 Aluminum Forging.

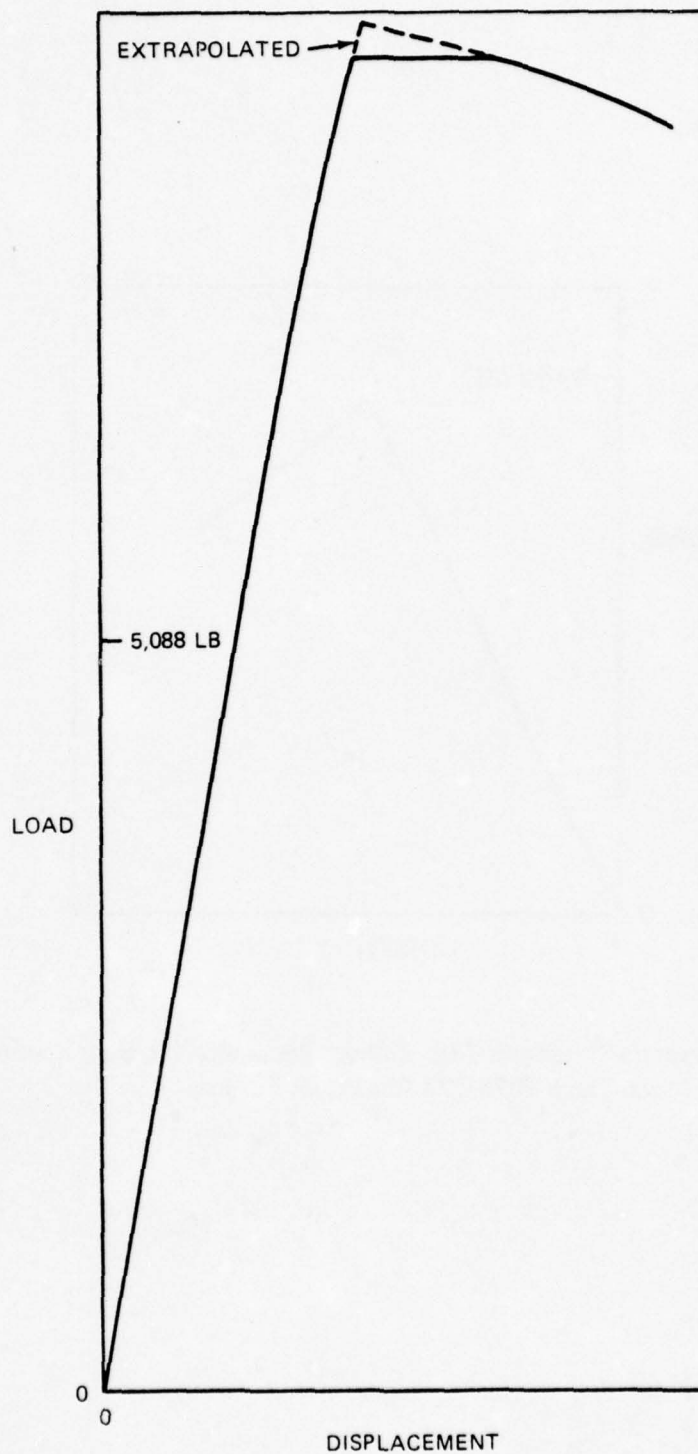


Figure C5. Fracture-Toughness Test of Longitudinal-Compact Specimen No. 0606, 6.7-Inch-Thick 7075-T73 Aluminum Forging.

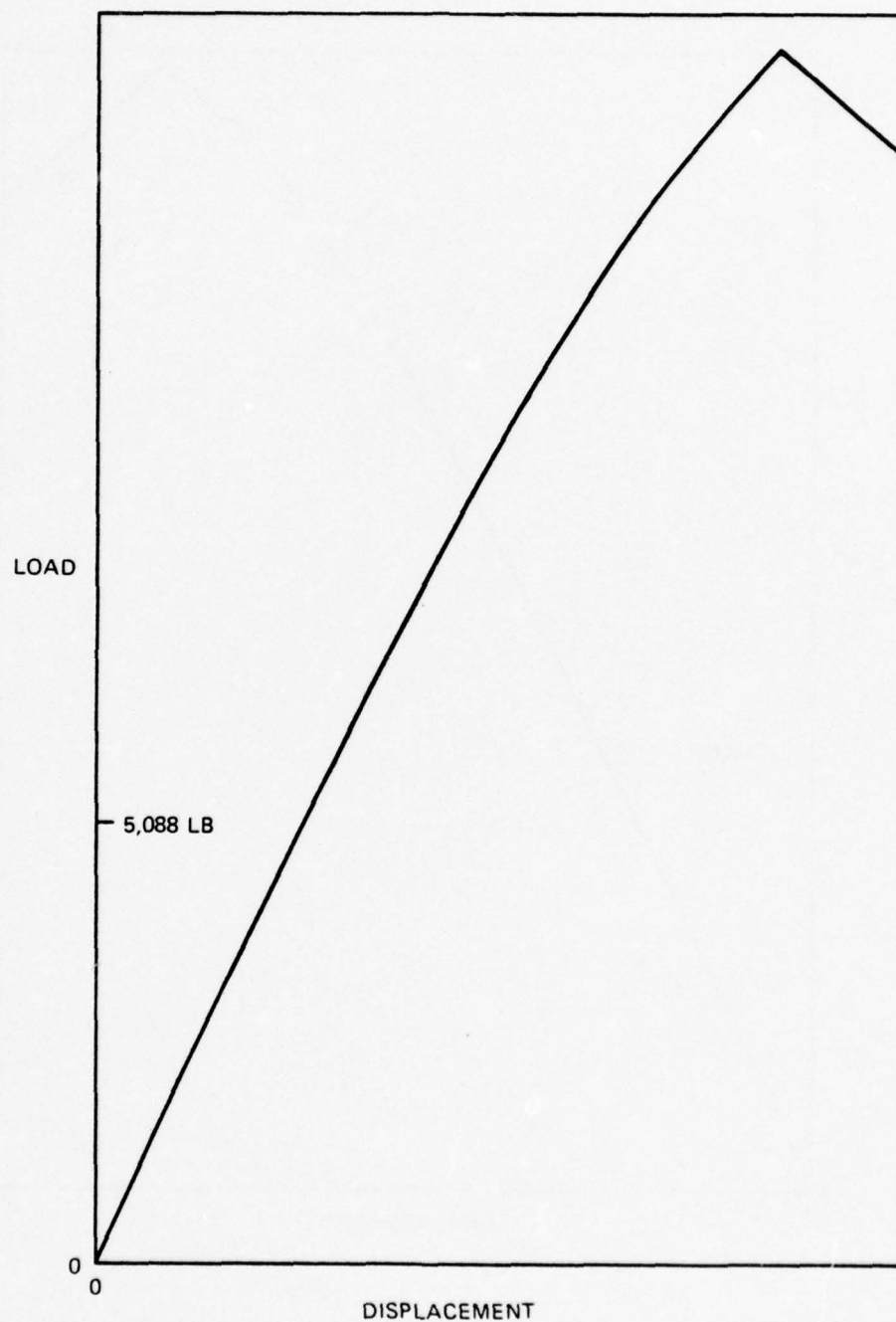


Figure C6. Fracture-Toughness Test of Longitudinal-Compact Specimen No. 0723, 1-Inch-Thick 7475-TMT1 Aluminum Forging.

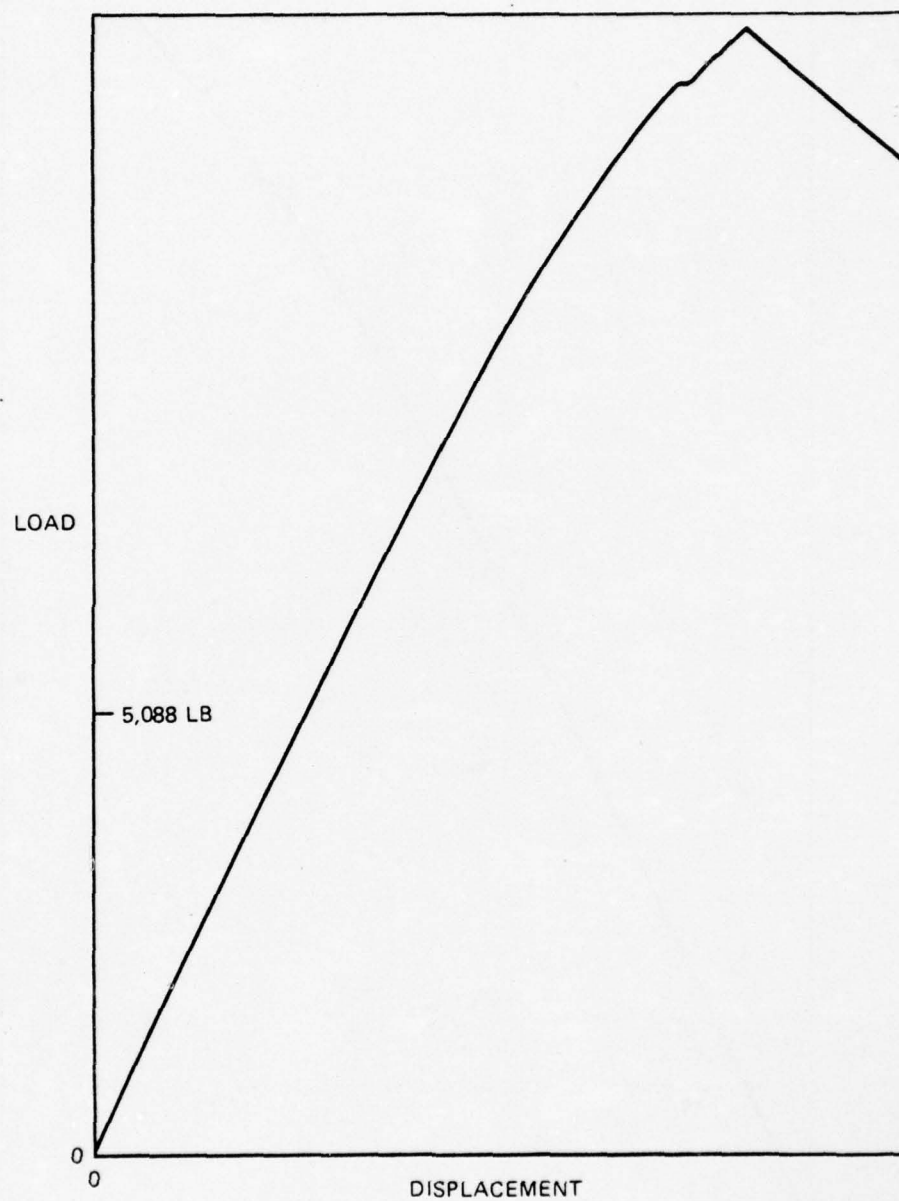


Figure C7. Fracture-Toughness Test of Longitudinal-Compact Specimen No. 0724, 1-Inch-Thick 7475-TMT1 Aluminum Forging.

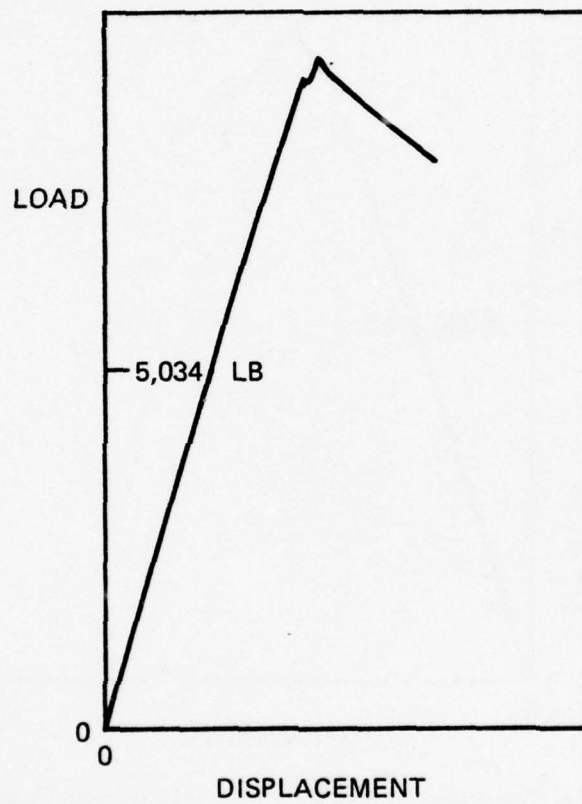


Figure C8. Fracture-Toughness Test of Longitudinal-Compact Specimen No. 0853, 2-Inch-Thick 7475-TMT1 Aluminum Forging.

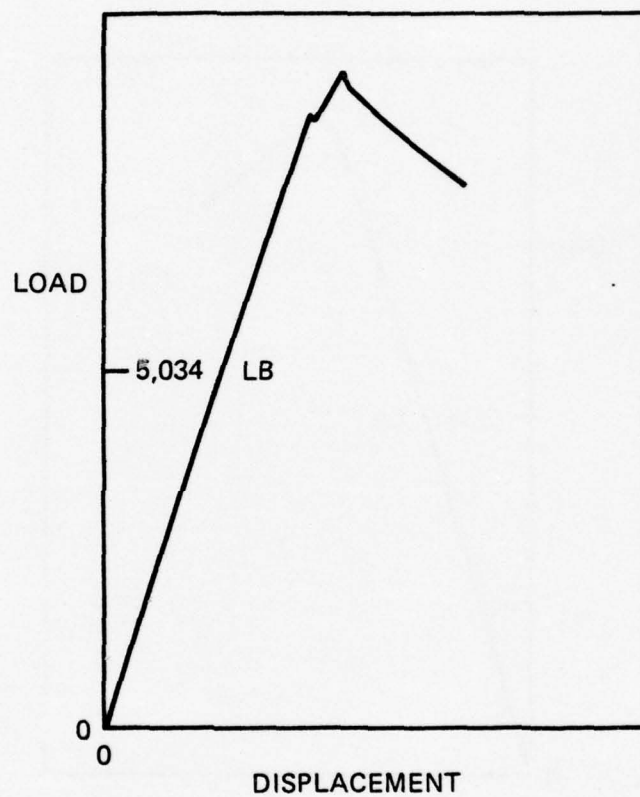


Figure C9. Fracture-Toughness Test of Longitudinal-Compact Specimen No. 0854, 2-Inch-Thick 7475-TMT1 Aluminum Forging.

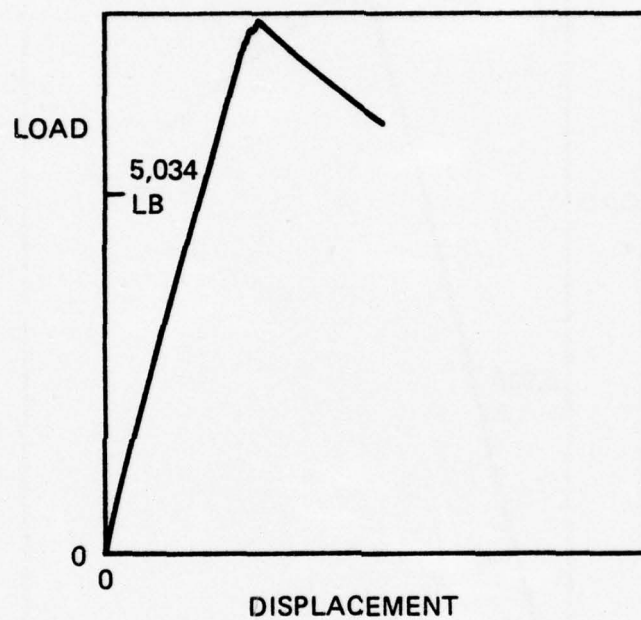


Figure C10. Fracture-Toughness Test of Short-Transverse-Compact Specimen No. 1001, 6.7-Inch-Thick 7475-TMT1 Aluminum Forging.

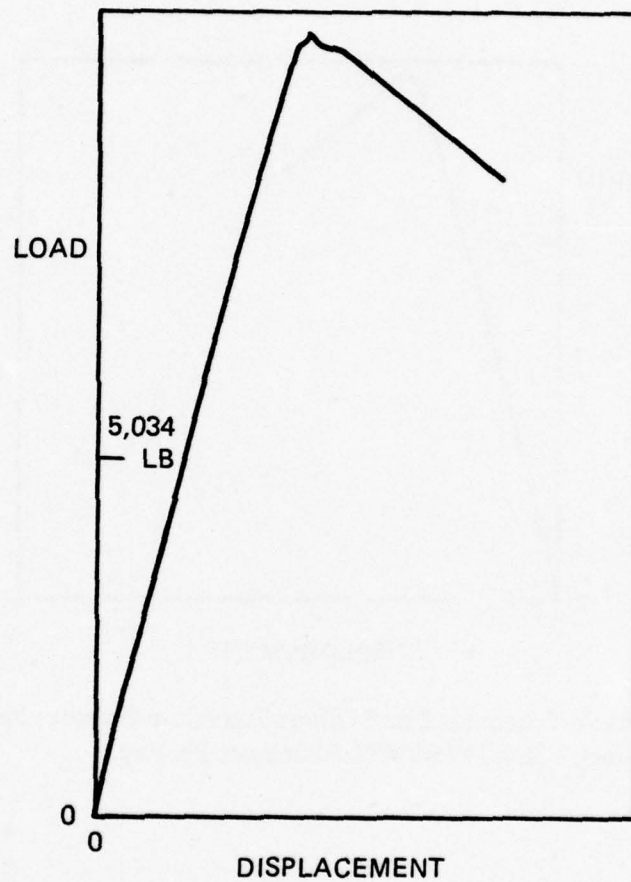


Figure C11. Fracture-Toughness Test of Longitudinal-Compact Specimen No. 1206, 6.7-Inch-Thick 7475-TMT1 Aluminum Forging.

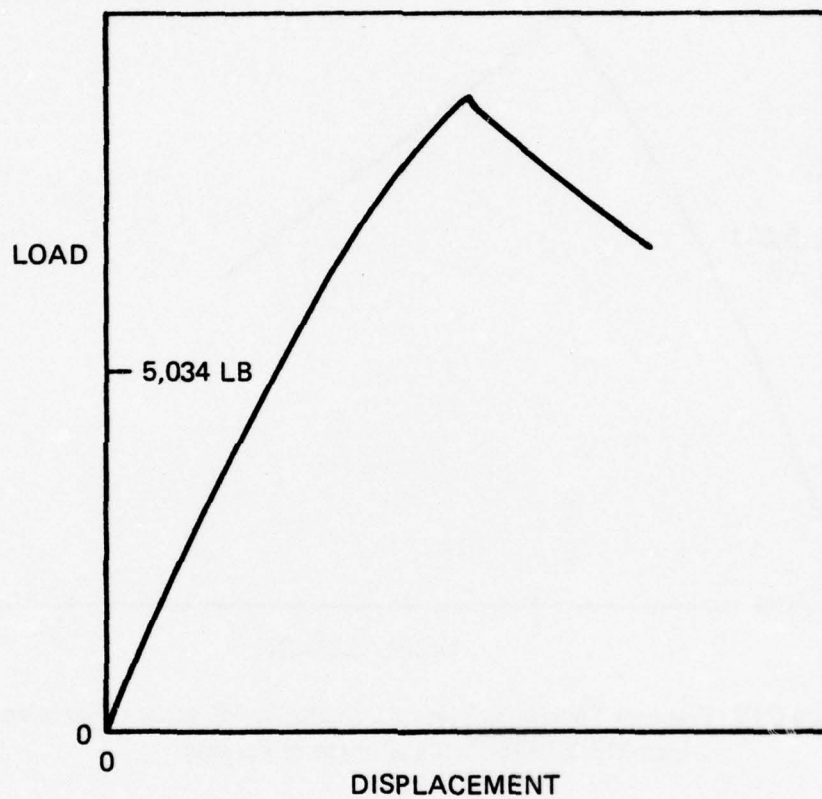


Figure C12. Fracture-Toughness Test of Longitudinal-Compact Specimen No. 1323, 1-Inch-Thick 7475-TMT2 Aluminum Forging.

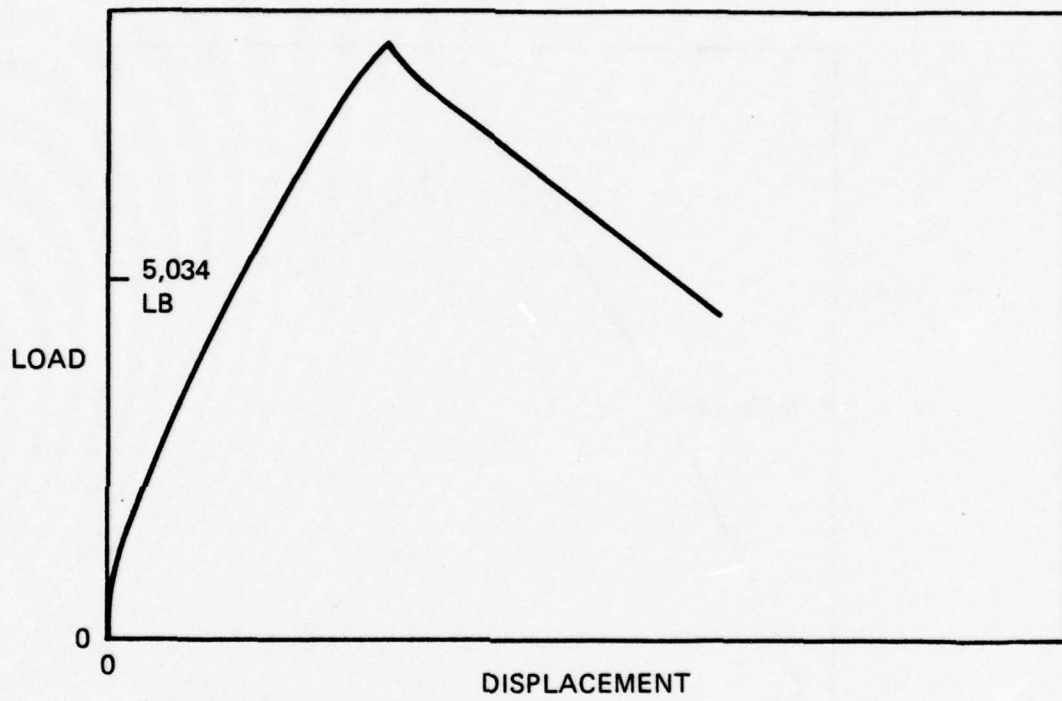


Figure C13. Fracture-Toughness Test of Longitudinal-Compact Specimen No. 1324, 1-Inch-Thick 7475-TMT2 Aluminum Forging.

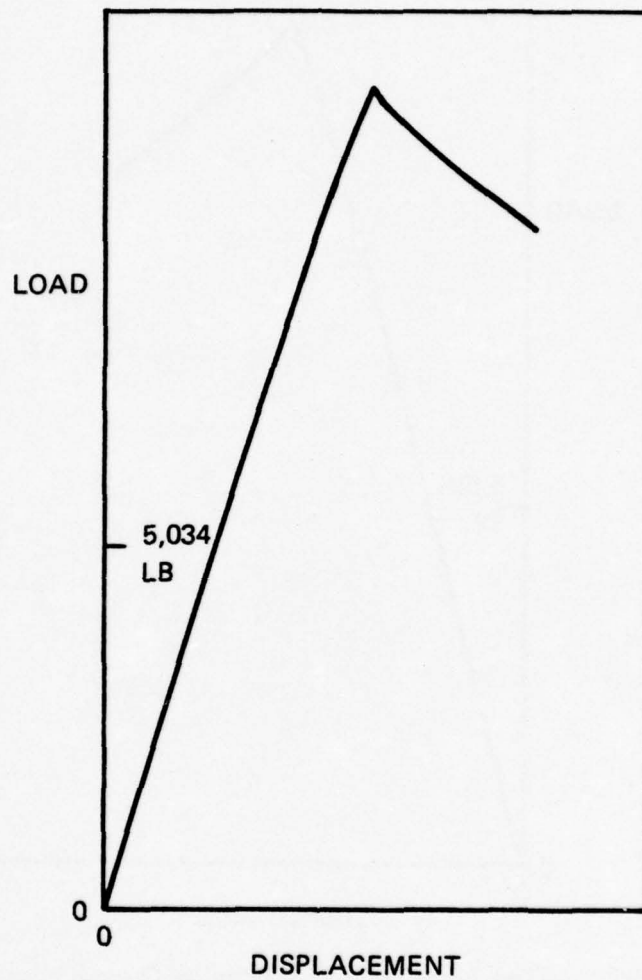


Figure C14. Fracture-Toughness Test of Longitudinal-Compact Specimen No. 1453, 2-Inch-Thick 7475-TMT2 Aluminum Forging.

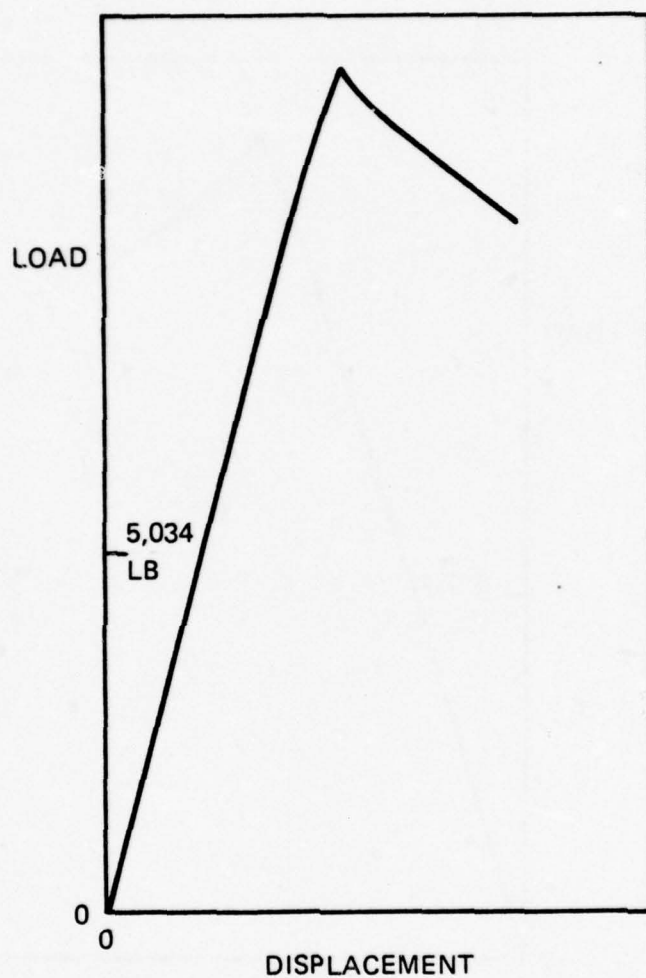


Figure C15. Fracture-Toughness Test of Longitudinal-Compact Specimen No. 1454, 2-Inch-Thick 7475-TMT2 Aluminum Forging.

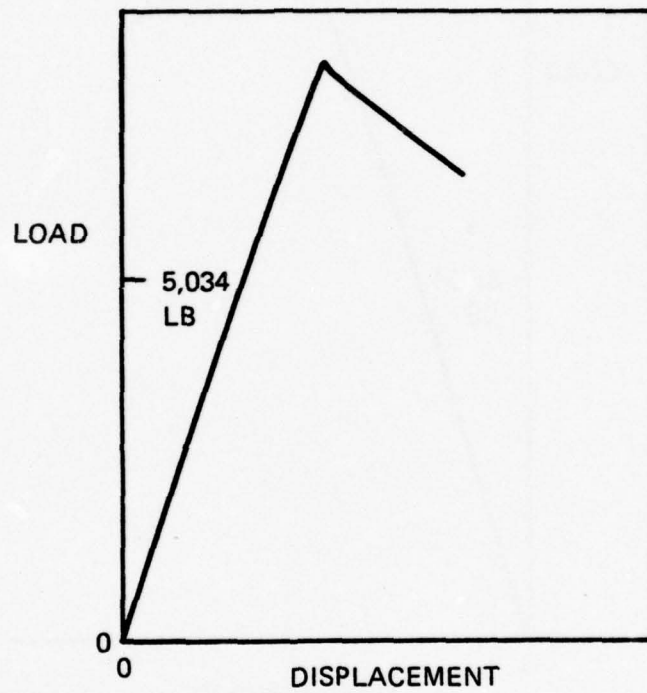


Figure C16. Fracture-Toughness Test of Short-Transverse-Compact Specimen No. 1601, 6.7-Inch-Thick 7475-TMT2 Aluminum Forging.

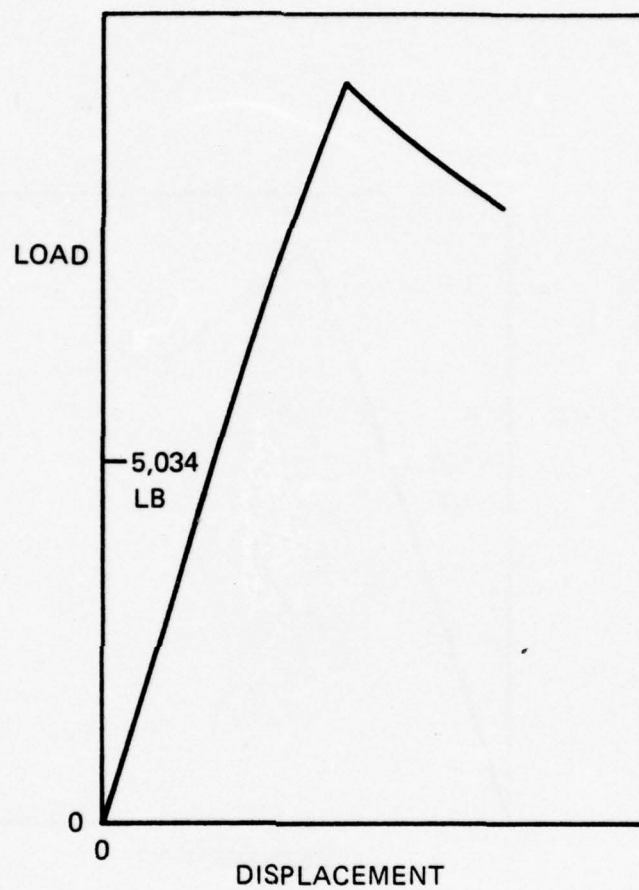


Figure C17. Fracture-Toughness Test of Longitudinal-Compact Specimen No. 1806, 6.7-Inch-Thick 7475-TMT2 Aluminum Forging.

APPENDIX D

FATIGUE-CRACK PROPAGATION-RATE DATA TABULATIONS

```

SJOB          ZOLA,KP=29,LINES=50,PAGES=90,TIME=30,RUN=CHECK
1    20  FORMAT(1H1,T10,'FATIGUE CRACK PROPAGATION DATA FOR 7475 TMT')
2    30  FORMAT(1H0,17A4)
3    2    FORMAT (/14X4HMAX,10X4HPMIN,10X2HAD10X2HNO10X1HB10X1HW)
4    3    FORMAT (12XF7.0,6XF7.0,6XF7.5,4XF7.0,7XF7.5,5XF7.5)
5    7    FORMAT (/6X1HA13X1HN9X4HDELA10X4HDELN8X4HKMAX7X4HDELK8X4HADN)
6    8    FORMAT(2XE11.5,3XF9.0,3XE11.5,1XF9.0,3XF8.2,3XF8.2,3XE11.5)
7    DIMENSION ALP(17),A(100),XN(100),DELK(100),DADN(100),DELA(100),DEL
      1N(100),XKMAX(100)
8    COMMON RDT(226)
9    EQUIVALENCE (RDT(10),PMAX),(RDT(11),PMIN),(RDT(12),B),(RDT(13),W),
      1(RDT(14),AO),(RDT(15),XNO),(RDT(16),XA),(RDT(17),A(1)),(RDT(116),X
      2N(1))
10   DO 69 I=1,226
11   69  RDT(I)=0.0
12   DO 15 I=1,17
13   15  ALP(I)=0.0
14   10  READ,N,M,(RDT(N+K-1),K=1,M)
15   IF(N=1)25,25,10
16   25  NN=RDT(1)+.01
17   IF(NN=1)60,70,55
18   55  READ9,(ALP(N),N=1,17)
19   9   FORMAT(17A4)
20   45  GO TO 10
21   70  DELP=PMAX=PMIN
22   COEF=DELP/(8*(W**0.5))
23   RATIO=PMAX/DELP
24   N=RDT(16)+.001
25   PRINT 20
26   PRINT 30,(ALP(K),K=1,17)
27   PRINT 2
28   PRINT 3,PMAX,PMIN,AO,XNO,B,W
29   PRINT 7
30   DELK(1)=COEF*(29.6*(A(1)/W)**0.5+655.7*(A(1)/W)**2.5+638.9*(A(1)/W
      1)**4.5+185.5*(A(1)/W)**1.5+1017.*(A(1)/W)**3.5)
31   XKMAX(1)=RATIO*DELK(1)
32   DELA(1)=A(1)=AO
33   DELN(1)=XN(1)=XNO
34   DADN(1)=DELA(1)/DELN(1)
35   PRINT 8,A(1),XN(1),DELA(1),DELN(1),XKMAX(1),DELK(1),DADN(1)
36   DO 100 J=2,N
37   DELK(J)=COEF*(29.6*(A(J)/W)**0.5+655.7*(A(J)/W)**2.5+638.9*(A(J)/W
      1)**4.5+185.5*(A(J)/W)**1.5+1017.*(A(J)/W)**3.5)
38   XKMAX(J)=RATIO*DELK(J)
39   DELA(J)=A(J)=A(J=1)
40   DELN(J)=XN(J)=XN(J=1)
41   DADN(J)=DELA(J)/DELN(J)
42   PRINT 8,A(J),XN(J),DELA(J),DELN(J),XKMAX(J),DELK(J),DADN(J)
43   100 CONTINUE
44   GO TO 10
45   60  STOP
46   END

```

SENTRY

FATIGUE CRACK PROPAGATION DATA

SPC NO 0121 LONG BEACH, CALIF. STRESS 1110 0.05 TEST FREQ 5 Hz

WAVE TIME	WAVE TIME	WAVE TIME	WAVE TIME	WAVE TIME	WAVE TIME
TIME	TIME	TIME	TIME	TIME	TIME
0.67360F 00	1.000000E-01	10000.00	10000.00	10000.00	0.104000E-04
0.71360F 00	1.000000E-01	10000.00	10000.00	10000.00	0.114000E-04
0.75360F 00	1.000000E-01	10000.00	10000.00	10000.00	0.124000E-04
0.79360F 00	1.000000E-01	10000.00	10000.00	10000.00	0.134000E-04
0.83360F 00	1.000000E-01	10000.00	10000.00	10000.00	0.144000E-04
0.87360F 00	1.000000E-01	10000.00	10000.00	10000.00	0.154000E-04
0.91360F 00	1.000000E-01	10000.00	10000.00	10000.00	0.164000E-04
0.95360F 00	1.000000E-01	10000.00	10000.00	10000.00	0.174000E-04
0.99360F 00	1.000000E-01	10000.00	10000.00	10000.00	0.184000E-04
0.103360F 01	1.000000E-01	10000.00	10000.00	10000.00	0.194000E-04
0.107360F 01	1.000000E-01	10000.00	10000.00	10000.00	0.204000E-04
0.111360F 01	1.000000E-01	10000.00	10000.00	10000.00	0.214000E-04
0.115360F 01	1.000000E-01	10000.00	10000.00	10000.00	0.224000E-04
0.119360F 01	1.000000E-01	10000.00	10000.00	10000.00	0.234000E-04
0.123360F 01	1.000000E-01	10000.00	10000.00	10000.00	0.244000E-04
0.127360F 01	1.000000E-01	10000.00	10000.00	10000.00	0.254000E-04
0.131360F 01	1.000000E-01	10000.00	10000.00	10000.00	0.264000E-04
0.135360F 01	1.000000E-01	10000.00	10000.00	10000.00	0.274000E-04
0.139360F 01	1.000000E-01	10000.00	10000.00	10000.00	0.284000E-04
0.143360F 01	1.000000E-01	10000.00	10000.00	10000.00	0.294000E-04
0.147360F 01	1.000000E-01	10000.00	10000.00	10000.00	0.304000E-04
0.151360F 01	1.000000E-01	10000.00	10000.00	10000.00	0.314000E-04
0.155360F 01	1.000000E-01	10000.00	10000.00	10000.00	0.324000E-04

FATIGUE CRACK PROPAGATION DATA

SPC NO 0121 LONG BEACH, CALIF. STRESS 1110 0.05 TEST FREQ 5 Hz

WAVE TIME	WAVE TIME	WAVE TIME	WAVE TIME	WAVE TIME	WAVE TIME
TIME	TIME	TIME	TIME	TIME	TIME
0.67430F 00	1.000000E-01	10000.00	10000.00	10000.00	0.112000E-04
0.71430F 00	1.000000E-01	10000.00	10000.00	10000.00	0.122000E-04
0.75430F 00	1.000000E-01	10000.00	10000.00	10000.00	0.132000E-04
0.79430F 00	1.000000E-01	10000.00	10000.00	10000.00	0.142000E-04
0.83430F 00	1.000000E-01	10000.00	10000.00	10000.00	0.152000E-04
0.87430F 00	1.000000E-01	10000.00	10000.00	10000.00	0.162000E-04
0.91430F 00	1.000000E-01	10000.00	10000.00	10000.00	0.172000E-04
0.95430F 00	1.000000E-01	10000.00	10000.00	10000.00	0.182000E-04
0.99430F 00	1.000000E-01	10000.00	10000.00	10000.00	0.192000E-04
0.10430F 01	1.000000E-01	10000.00	10000.00	10000.00	0.202000E-04
0.10830F 01	1.000000E-01	10000.00	10000.00	10000.00	0.212000E-04
0.11230F 01	1.000000E-01	10000.00	10000.00	10000.00	0.222000E-04
0.11630F 01	1.000000E-01	10000.00	10000.00	10000.00	0.232000E-04
0.12030F 01	1.000000E-01	10000.00	10000.00	10000.00	0.242000E-04
0.12430F 01	1.000000E-01	10000.00	10000.00	10000.00	0.252000E-04
0.12830F 01	1.000000E-01	10000.00	10000.00	10000.00	0.262000E-04
0.13230F 01	1.000000E-01	10000.00	10000.00	10000.00	0.272000E-04
0.13630F 01	1.000000E-01	10000.00	10000.00	10000.00	0.282000E-04
0.14030F 01	1.000000E-01	10000.00	10000.00	10000.00	0.292000E-04
0.14430F 01	1.000000E-01	10000.00	10000.00	10000.00	0.302000E-04
0.14830F 01	1.000000E-01	10000.00	10000.00	10000.00	0.312000E-04
0.15230F 01	1.000000E-01	10000.00	10000.00	10000.00	0.322000E-04

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FATIGUE CRACK PROPAGATION DATA
SPEC NO 0122 LONG GRAIN ROOM SALT TEST F 5 HZ

	PMAX 5600	PMIN 200	ΔP 0.63900	ΔU 0	ΔK 0.24000	ΔK 2.50000
A	N	DELA	DELN	MAX	DELK	DATA
0.67940E 00	3270.	0.40000E-01	3270.	7892.97	7498.33	0.12232E-04
0.71940E 00	5610.	0.40000E-01	2340.	8104.13	7648.92	0.17044E-04
0.75940E 00	7710.	0.40000E-01	2100.	8348.05	7928.75	0.19044E-04
0.79940E 00	9660.	0.40000E-01	1950.	8617.21	8180.36	0.20513E-04
0.83940E 00	11400.	0.40000E-01	1740.	8910.02	8470.23	0.22489E-04
0.87940E 00	13050.	0.40000E-01	1650.	9241.21	8779.15	0.24242E-04
0.91940E 00	14610.	0.40000E-01	1560.	9591.99	9112.39	0.25841E-04
0.95940E 00	16110.	0.40000E-01	1500.	9967.94	9469.54	0.26667E-04
0.99940E 00	17370.	0.40000E-01	1260.	10307.26	9850.80	0.31706E-04
0.10394E 01	18600.	0.40000E-01	1230.	10797.19	10257.34	0.32520E-04
0.10794E 01	19860.	0.40000E-01	1260.	11253.49	10690.73	0.31740E-04
0.11194E 01	20470.	0.40000E-01	1110.	11740.95	11153.91	0.36046E-04
0.11594E 01	21810.	0.40000E-01	840.	12263.61	11650.43	0.47619E-04
0.11994E 01	22830.	0.40000E-01	1020.	12828.28	12184.47	0.49216E-04
0.12394E 01	24480.	0.40000E-01	1050.	13435.15	12763.40	0.38099E-04
0.12794E 01	24480.	0.40000E-01	600.	14097.63	13342.75	0.60667E-04
0.13194E 01	25140.	0.40000E-01	600.	14822.65	14081.52	0.60667E-04
0.13594E 01	25400.	0.40000E-01	600.	15620.10	14839.10	0.60667E-04
0.13994E 01	26430.	0.40000E-01	630.	16501.87	15670.78	0.63492E-04

FATIGUE CRACK PROPAGATION DATA
SPEC NO 0122 LONG GRAIN ROOM SALT TEST F 5 HZ

	PMAX 770	PMIN 30	ΔP 0.72570	ΔU 0	ΔK 0.24970	ΔK 2.50000
A	N	DELA	DELN	MAX	DELK	DATA
0.76570E 00	2430.	0.40000E-01	2430.	11095.76	11095.04	0.16041E-04
0.80570E 00	4740.	0.40000E-01	2310.	12064.63	11460.63	0.17314E-04
0.84570E 00	6870.	0.40000E-01	2130.	12488.70	11861.57	0.18779E-04
0.88570E 00	8910.	0.40000E-01	2040.	12944.26	12297.18	0.19604E-04
0.92570E 00	10650.	0.40000E-01	1740.	13439.29	12766.07	0.22064E-04
0.96570E 00	12390.	0.40000E-01	1740.	13968.42	13249.11	0.22064E-04
0.10057E 01	13890.	0.40000E-01	1500.	14533.07	13805.50	0.26667E-04
0.10457E 01	15000.	0.40000E-01	1110.	15135.01	14377.30	0.36046E-04
0.10857E 01	16320.	0.40000E-01	1320.	15777.10	14987.25	0.30603E-04
0.11257E 01	17790.	0.40000E-01	1470.	16463.30	15630.14	0.27211E-04
0.11657E 01	18690.	0.40000E-01	900.	17194.57	16334.50	0.44004E-04
0.12057E 01	19770.	0.40000E-01	1080.	17992.88	17091.91	0.47037E-04
0.12457E 01	20540.	0.40000E-01	810.	18851.88	17907.49	0.44004E-04
0.12857E 01	21390.	0.40000E-01	810.	19781.36	18796.74	0.44004E-04
0.13257E 01	22200.	0.40000E-01	810.	20811.94	19770.02	0.44004E-04
0.13657E 01	22830.	0.40000E-01	630.	21440.05	20841.86	0.63492E-04
0.14057E 01	23490.	0.40000E-01	600.	23188.17	22027.29	0.60667E-04
0.14457E 01	24030.	0.40000E-01	540.	24574.17	23344.86	0.70174E-04
0.14857E 01	24600.	0.40000E-01	570.	26121.65	24813.91	0.70174E-04
0.15257E 01	24930.	0.40000E-01	430.	27851.28	26456.46	0.12121E-03
0.15657E 01	25340.	0.40000E-01	450.	29789.51	28298.14	0.22064E-04
0.16057E 01	25680.	0.40000E-01	300.	31844.29	30364.05	0.13333E-03
0.16457E 01	25860.	0.40000E-01	180.	34408.24	32861.74	0.22064E-04
0.16857E 01	25940.	0.40000E-01	120.	37148.77	35282.97	0.13333E-03
0.17257E 01	26100.	0.40000E-01	120.	40228.84	38210.80	0.13333E-03
0.17657E 01	26160.	0.40000E-01	60.	43684.21	41498.27	0.60667E-04
0.18057E 01	26190.	0.40000E-01	30.	47555.21	45174.42	0.13333E-03
0.18457E 01	26220.	0.40000E-01	30.	51887.74	49290.07	0.13333E-03

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SPACED OUT LETTERS WITH NO SPACES & NO PUNCTUATION

114.	115.	116.	117.	118.	119.	120.	121.	122.	123.	124.	125.	126.	127.	128.	129.	130.	131.	132.	133.	134.	135.	136.	137.	138.	139.	140.	141.	142.	143.	144.	145.	146.	147.	148.	149.	150.	151.	152.	153.	154.	155.	156.	157.	158.	159.	160.	161.	162.	163.	164.	165.	166.	167.	168.	169.	170.	171.	172.	173.	174.	175.	176.	177.	178.	179.	180.	181.	182.	183.	184.	185.	186.	187.	188.	189.	190.	191.	192.	193.	194.	195.	196.	197.	198.	199.	200.	201.	202.	203.	204.	205.	206.	207.	208.	209.	210.	211.	212.	213.	214.	215.	216.	217.	218.	219.	220.	221.	222.	223.	224.	225.	226.	227.	228.	229.	230.	231.	232.	233.	234.	235.	236.	237.	238.	239.	240.	241.	242.	243.	244.	245.	246.	247.	248.	249.	250.	251.	252.	253.	254.	255.	256.	257.	258.	259.	260.	261.	262.	263.	264.	265.	266.	267.	268.	269.	270.	271.	272.	273.	274.	275.	276.	277.	278.	279.	280.	281.	282.	283.	284.	285.	286.	287.	288.	289.	290.	291.	292.	293.	294.	295.	296.	297.	298.	299.	300.	301.	302.	303.	304.	305.	306.	307.	308.	309.	310.	311.	312.	313.	314.	315.	316.	317.	318.	319.	320.	321.	322.	323.	324.	325.	326.	327.	328.	329.	330.	331.	332.	333.	334.	335.	336.	337.	338.	339.	340.	341.	342.	343.	344.	345.	346.	347.	348.	349.	350.	351.	352.	353.	354.	355.	356.	357.	358.	359.	360.	361.	362.	363.	364.	365.	366.	367.	368.	369.	370.	371.	372.	373.	374.	375.	376.	377.	378.	379.	380.	381.	382.	383.	384.	385.	386.	387.	388.	389.	390.	391.	392.	393.	394.	395.	396.	397.	398.	399.	400.	401.	402.	403.	404.	405.	406.	407.	408.	409.	410.	411.	412.	413.	414.	415.	416.	417.	418.	419.	420.	421.	422.	423.	424.	425.	426.	427.	428.	429.	430.	431.	432.	433.	434.	435.	436.	437.	438.	439.	440.	441.	442.	443.	444.	445.	446.	447.	448.	449.	450.	451.	452.	453.	454.	455.	456.	457.	458.	459.	460.	461.	462.	463.	464.	465.	466.	467.	468.	469.	470.	471.	472.	473.	474.	475.	476.	477.	478.	479.	480.	481.	482.	483.	484.	485.	486.	487.	488.	489.	490.	491.	492.	493.	494.	495.	496.	497.	498.	499.	500.	501.	502.	503.	504.	505.	506.	507.	508.	509.	510.	511.	512.	513.	514.	515.	516.	517.	518.	519.	520.	521.	522.	523.	524.	525.	526.	527.	528.	529.	530.	531.	532.	533.	534.	535.	536.	537.	538.	539.	540.	541.	542.	543.	544.	545.	546.	547.	548.	549.	550.	551.	552.	553.	554.	555.	556.	557.	558.	559.	560.	561.	562.	563.	564.	565.	566.	567.	568.	569.	570.	571.	572.	573.	574.	575.	576.	577.	578.	579.	580.	581.	582.	583.	584.	585.	586.	587.	588.	589.	590.	591.	592.	593.	594.	595.	596.	597.	598.	599.	600.	601.	602.	603.	604.	605.	606.	607.	608.	609.	610.	611.	612.	613.	614.	615.	616.	617.	618.	619.	620.	621.	622.	623.	624.	625.	626.	627.	628.	629.	630.	631.	632.	633.	634.	635.	636.	637.	638.	639.	640.	641.	642.	643.	644.	645.	646.	647.	648.	649.	650.	651.	652.	653.	654.	655.	656.	657.	658.	659.	660.	661.	662.	663.	664.	665.	666.	667.	668.	669.	670.	671.	672.	673.	674.	675.	676.	677.	678.	679.	680.	681.	682.	683.	684.	685.	686.	687.	688.	689.	690.	691.	692.	693.	694.	695.	696.	697.	698.	699.	700.	701.	702.	703.	704.	705.	706.	707.	708.	709.	710.	711.	712.	713.	714.	715.	716.	717.	718.	719.	720.	721.	722.	723.	724.	725.	726.	727.	728.	729.	730.	731.	732.	733.	734.	735.	736.	737.	738.	739.	740.	741.	742.	743.	744.	745.	746.	747.	748.	749.	750.	751.	752.	753.	754.	755.	756.	757.	758.	759.	760.	761.	762.	763.	764.	765.	766.	767.	768.	769.	770.	771.	772.	773.	774.	775.	776.	777.	778.	779.	780.	781.	782.	783.	784.	785.	786.	787.	788.	789.	790.	791.	792.	793.	794.	795.	796.	797.	798.	799.	800.	801.	802.	803.	804.	805.	806.	807.	808.	809.	810.	811.	812.	813.	814.	815.	816.	817.	818.	819.	820.	821.	822.	823.	824.	825.	826.	827.	828.	829.	830.	831.	832.	833.	834.	835.	836.	837.	838.	839.	840.	841.	842.	843.	844.	845.	846.	847.	848.	849.	850.	851.	852.	853.	854.	855.	856.	857.	858.	859.	860.	861.	862.	863.	864.	865.	866.	867.	868.	869.	870.	871.	872.	873.	874.	875.	876.	877.	878.	879.	880.	881.	882.	883.	884.	885.	886.	887.	888.	889.	890.	891.	892.	893.	894.	895.	896.	897.	898.	899.	900.	901.	902.	903.	904.	905.	906.	907.	908.	909.	910.	911.	912.	913.	914.	915.	916.	917.	918.	919.	920.	921.	922.	923.	924.	925.	926.	927.	928.	929.	930.	931.	932.	933.	934.	935.	936.	937.	938.	939.	940.	941.	942.	943.	944.	945.	946.	947.	948.	949.	950.	951.	952.	953.	954.	955.	956.	957.	958.	959.	960.	961.	962.	963.	964.	965.	966.	967.	968.	969.	970.	971.	972.	973.	974.	975.	976.	977.	978.	979.	980.	981.	982.	983.	984.	985.	986.	987.	988.	989.	990.	991.	992.	993.	994.	995.	996.	997.	998.	999.	1000.
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SPC No. 0222 Using only one test stress = 110 0.05 Test Error = 0.02

[illegible]

FATIGUE CRACK PROPAGATION DATA

SPEC NO 0801 THIN GRAIN ROOM AIR STRESS RATIO 0.05 TEST FREQ 5 HZ

A	PMAX 497.	PMIN 25.	AU 0.04250	NU 0.	B 0.27100	N 2.50000
A	N	DELA	DELN	KMAX	DELK	DAWN
0.71210E 00	6120.	0.40000E-01	6120.	4184.05	7473.76	0.43573E-05
0.72210E 00	10740.	0.40000E-01	7010.	4635.06	8207.55	0.44438E-05
0.74210E 00	25500.	0.40000E-01	7740.	5512.37	8470.57	0.51680E-05
0.43210E 00	41170.	0.40000E-01	8240.	5218.11	8701.15	0.64102E-05
0.47210E 00	37400.	0.40000E-01	7030.	5551.53	9076.05	0.66335E-05
0.41210E 00	42710.	0.40000E-01	5310.	5411.75	9420.41	0.75330E-05
0.44210E 00	47220.	0.40000E-01	4710.	10294.05	4787.50	0.44926E-05
0.94210E 00	51120.	0.40000E-01	3900.	10710.40	10174.85	0.10750E-04
0.10321E 01	54370.	0.40000E-01	4750.	11150.40	10544.10	0.10667E-04
0.10721E 01	57800.	0.40000E-01	2730.	11620.01	11043.98	0.14652E-04
0.11121E 01	60140.	0.40000E-01	2540.	12121.11	11520.25	0.15504E-04
0.11521E 01	61420.	0.40000E-01	1740.	12557.70	12030.33	0.22988E-04
0.11921E 01	63440.	0.40000E-01	7040.	13234.22	12574.13	0.19608E-04
0.12321E 01	65220.	0.40000E-01	1260.	13854.51	13172.47	0.31740E-04
0.12721E 01	66270.	0.40000E-01	1030.	14537.45	13617.27	0.38095E-04
0.13121E 01	67410.	0.40000E-01	1140.	15274.71	14222.27	0.35088E-04
0.13521E 01	67420.	0.40000E-01	510.	16044.74	15244.94	0.78431E-04
0.13921E 01	67410.	0.40000E-01	390.	16794.38	16122.44	0.10750E-03
0.14321E 01	67520.	0.40000E-01	210.	17944.59	17102.57	0.19040E-03
0.14721E 01	67530.	0.40000E-01	50.	19107.41	18100.23	0.13333E-02
0.15121E 01	67500.	0.40000E-01	50.	20350.44	19342.11	0.13333E-02

FATIGUE CRACK PROPAGATION DATA

SPEC NO 0805 LONG GRAIN ROOM SALT TEST F 5 HZ

A	PMAX 497.	PMIN 25.	AU 0.04250	NU 0.	B 0.24960	N 2.50000
A	N	DELA	DELN	KMAX	DELK	DAWN
0.68250E 00	6120.	0.40000E-01	6120.	7029.80	6676.19	0.65360E-05
0.72250E 00	10740.	0.40000E-01	4620.	7219.64	6856.49	0.86580E-05
0.76250E 00	14880.	0.40000E-01	4140.	7436.75	7062.68	0.96618E-05
0.80250E 00	18990.	0.40000E-01	4110.	7679.76	7293.46	0.97324E-05
0.84250E 00	22500.	0.40000E-01	3510.	7947.23	7547.48	0.11396E-04
0.88250E 00	25620.	0.40000E-01	3120.	8238.12	7823.73	0.12821E-04
0.92250E 00	28020.	0.40000E-01	2400.	8551.63	8121.47	0.16667E-04
0.96250E 00	31140.	0.40000E-01	3120.	8887.52	8440.47	0.12821E-04
0.10025E 01	33540.	0.40000E-01	2400.	9246.07	8780.99	0.16666E-04
0.10425E 01	35490.	0.40000E-01	1950.	9628.34	9144.02	0.20513E-04
0.10825E 01	37530.	0.40000E-01	2040.	10036.00	9531.18	0.19608E-04
0.11225E 01	39060.	0.40000E-01	1530.	10471.65	9944.89	0.26144E-04
0.11625E 01	40560.	0.40000E-01	1500.	10938.80	10388.57	0.26667E-04
0.12025E 01	41820.	0.40000E-01	1260.	11441.92	10866.38	0.31740E-04
0.12425E 01	42750.	0.40000E-01	930.	11986.59	11383.66	0.43011E-04
0.12825E 01	43660.	0.40000E-01	1110.	12574.60	11946.83	0.36036E-04
0.13225E 01	44640.	0.40000E-01	780.	13228.63	12563.22	0.51282E-04
0.13625E 01	45600.	0.40000E-01	960.	13943.03	13241.68	0.41667E-04
0.14025E 01	46290.	0.40000E-01	690.	14733.09	13992.00	0.57971E-04
0.14425E 01	46950.	0.40000E-01	660.	15610.77	14825.54	0.60606E-04
0.14825E 01	47430.	0.40000E-01	480.	16588.96	15754.54	0.83333E-04
0.15225E 01	47700.	0.40000E-01	270.	17683.18	16793.70	0.14815E-03
0.15625E 01	47910.	0.40000E-01	210.	18908.62	17957.50	0.19040E-03
0.16025E 01	48030.	0.40000E-01	120.	20264.17	19263.86	0.33333E-03

COPY AVAILABLE TO DDC DOES NOT
PERMIT FULLY LEGIBLE PRODUCTION

FATIGUE CRACK PROPAGATION DATA
SPEC. NO. 0604 LONG GRAIN ROOM SALT TEST F 5 HZ

	MAX STRESS	MIN STRESS	AG 0.79290	NO 0.	H 0.25000	A 2.50000
A		DELTA	DELTA	MAX	DELTA	DA/DN
0.83290E-00	5180.	0.40000E-01	5180.	9831.36	9340.81	0.12579E-04
0.87290E-00	5540.	0.40000E-01	2400.	10187.36	9678.82	0.16667E-04
0.91290E-00	6010.	0.40000E-01	2430.	10571.67	10043.95	0.16461E-04
0.95290E-00	10020.	0.40000E-01	2010.	10984.07	10435.75	0.19901E-04
0.99290E-00	11700.	0.40000E-01	1680.	11424.52	10854.22	0.23810E-04
0.10329E-01	15800.	0.40000E-01	2100.	11894.03	11400.30	0.19048E-04
0.10729E-01	15420.	0.40000E-01	1620.	12344.76	11776.03	0.24691E-04
0.11129E-01	17220.	0.40000E-01	1800.	12929.50	12284.07	0.22222E-04
0.11529E-01	18720.	0.40000E-01	1500.	14502.35	12878.33	0.26667E-04
0.11929E-01	19950.	0.40000E-01	1230.	14118.70	13413.91	0.42520E-04
0.12329E-01	21240.	0.40000E-01	1290.	14785.06	14047.01	0.31008E-04
0.12729E-01	22260.	0.40000E-01	1020.	15509.49	14735.26	0.34216E-04
0.13129E-01	23240.	0.40000E-01	1020.	16301.35	15487.61	0.39216E-04
0.13529E-01	24210.	0.40000E-01	930.	17171.92	16314.71	0.45011E-04
0.13929E-01	24990.	0.40000E-01	780.	18133.66	17228.45	0.51288E-04
0.14329E-01	25850.	0.40000E-01	680.	19203.40	18242.32	0.60606E-04
0.14729E-01	26220.	0.40000E-01	570.	20449.54	19471.71	0.70175E-04
0.15129E-01	26670.	0.40000E-01	450.	21717.98	20833.85	0.86666E-04
0.15529E-01	27140.	0.40000E-01	510.	23205.36	22046.98	0.78431E-04
0.15929E-01	27600.	0.40000E-01	420.	24874.43	23632.73	0.95238E-04
0.16329E-01	28050.	0.40000E-01	450.	26747.45	25412.72	0.86666E-04
0.16729E-01	28410.	0.40000E-01	380.	28451.84	27411.59	0.11111E-03
0.17129E-01	28710.	0.40000E-01	300.	31210.79	29650.58	0.13333E-03
0.17529E-01	28940.	0.40000E-01	270.	33866.65	32176.07	0.14415E-03
0.17929E-01	29190.	0.40000E-01	210.	36839.18	35000.19	0.19048E-03
0.18329E-01	29310.	0.40000E-01	120.	40167.98	38122.84	0.33333E-03
0.18729E-01	29450.	0.40000E-01	120.	43669.57	41696.65	0.33333E-03
0.19129E-01	29490.	0.40000E-01	80.	48043.02	46644.77	0.66667E-03
0.19529E-01	29550.	0.40000E-01	80.	52877.55	50041.29	0.66667E-03
0.19929E-01	29810.	0.40000E-01	80.	57818.63	54930.49	0.66667E-03

FATIGUE CRACK PROPAGATION DATA
SPECIMEN NO. 0605 LONG GRAIN ROOM AIR STRESS RATIO 0.05 TEST

	MAX STRESS	MIN STRESS	AG 0.79290	NO 0.	H 0.25000	A 2.50000
A		DELTA	DELTA	MAX	DELTA	DA/DN
0.64100E-00	3270.	0.40000E-01	3270.	10464.30	10415.39	0.17732E-04
0.72100E-00	4420.	0.40000E-01	4150.	11254.07	10645.40	0.12649E-04
0.76100E-00	4060.	0.40000E-01	2690.	11596.43	11015.88	0.15152E-04
0.80100E-00	11140.	0.40000E-01	2290.	11974.32	11374.45	0.17544E-04
0.84100E-00	11540.	0.40000E-01	2250.	12340.47	11770.16	0.17778E-04
0.88100E-00	11940.	0.40000E-01	2400.	12843.24	12200.27	0.16667E-04
0.92100E-00	17840.	0.40000E-01	1650.	13331.41	12666.00	0.24262E-04
0.96100E-00	17550.	0.40000E-01	2010.	13854.39	13160.79	0.19901E-04
0.10010E-01	21440.	0.40000E-01	1680.	14412.44	13811.38	0.23810E-04
0.10410E-01	22420.	0.40000E-01	1590.	15004.21	14256.45	0.25157E-04
0.10810E-01	24270.	0.40000E-01	1350.	15643.05	14854.90	0.24630E-04
0.11210E-01	25330.	0.40000E-01	1260.	16121.41	15504.31	0.31746E-04
0.11610E-01	26570.	0.40000E-01	1140.	17048.77	16195.25	0.35088E-04
0.12010E-01	27410.	0.40000E-01	1140.	17832.01	16939.26	0.35088E-04
0.12410E-01	28440.	0.40000E-01	1050.	18674.72	17744.55	0.34095E-04
0.12810E-01	29740.	0.40000E-01	930.	19602.37	18521.01	0.43011E-04
0.13210E-01	30570.	0.40000E-01	750.	20612.20	19500.28	0.51262E-04
0.13610E-01	31440.	0.40000E-01	870.	21723.27	20635.73	0.45977E-04
0.14010E-01	32100.	0.40000E-01	680.	22452.02	21402.46	0.60606E-04
0.14410E-01	32730.	0.40000E-01	630.	24316.68	23044.30	0.63492E-04
0.14810E-01	33360.	0.40000E-01	630.	25837.75	24444.22	0.63492E-04
0.15210E-01	34400.	0.40000E-01	540.	27538.16	26154.52	0.74074E-04
0.15610E-01	34410.	0.40000E-01	510.	29444.50	27469.46	0.78431E-04
0.16010E-01	34440.	0.40000E-01	450.	31881.62	30000.53	0.88888E-04
0.16410E-01	35110.	0.40000E-01	450.	33481.77	32240.53	0.88888E-04
0.16810E-01	35640.	0.40000E-01	350.	36877.12	34440.44	0.12121E-03
0.17210E-01	35740.	0.40000E-01	150.	37704.23	37716.50	0.24667E-03
0.17610E-01	35440.	0.40000E-01	80.	43101.07	40443.28	0.44444E-03

FATIGUE CRACK PROPAGATION DATA

SPEC NO 0720 LONG GRAIN ROOM AIR TEST FREQ 5 HZ

	PMAX 779.	PMIN 39.	AO 0.60540	NO 0.	B 0.25040	W 2.50000
A	N	DELA	DELN	KMAX	DELK	DADN
0.60540E 00	4800.	0.00000E 00	4800.	10539.83	10012.17	0.00000E 00
0.64540E 00	8910.	0.40000E-01	4110.	10748.29	10210.20	0.97324E-05
0.68540E 00	12750.	0.40000E-01	3840.	11003.32	10452.46	0.10417E-04
0.72540E 00	16200.	0.40000E-01	3450.	11303.14	10737.27	0.11594E-04
0.76540E 00	19380.	0.40000E-01	3180.	11645.41	11062.40	0.12579E-04
0.80540E 00	22320.	0.40000E-01	2940.	12027.87	11425.71	0.13605E-04
0.84540E 00	24930.	0.40000E-01	2610.	12448.49	11825.27	0.15326E-04
0.88540E 00	27450.	0.40000E-01	2520.	12905.55	12259.46	0.15873E-04
0.92540E 00	29400.	0.40000E-01	1950.	13397.96	12727.21	0.20513E-04
0.96540E 00	31500.	0.40000E-01	2100.	13925.25	13228.11	0.19048E-04
0.10054E 01	33150.	0.40000E-01	1650.	14488.06	13762.74	0.24242E-04
0.10454E 01	34680.	0.40000E-01	1530.	15088.04	14332.68	0.26144E-04
0.10854E 01	36180.	0.40000E-01	1500.	15728.07	14940.67	0.26667E-04
0.11254E 01	37530.	0.40000E-01	1350.	16412.00	15590.36	0.29630E-04
0.11654E 01	38640.	0.40000E-01	1110.	17145.66	16287.29	0.36036E-04
0.12054E 01	39660.	0.40001E-01	1020.	17936.20	17038.25	0.39217E-04
0.12454E 01	40650.	0.40000E-01	990.	18792.36	17851.55	0.40404E-04
0.12854E 01	41580.	0.40000E-01	930.	19724.72	18737.23	0.43011E-04
0.13254E 01	42330.	0.40000E-01	750.	20745.74	19707.14	0.53333E-04
0.13654E 01	43110.	0.40000E-01	780.	21869.80	20774.92	0.51282E-04
0.14054E 01	43740.	0.40000E-01	630.	23113.50	21956.36	0.63492E-04
0.14454E 01	44280.	0.40000E-01	540.	24495.48	23269.16	0.74074E-04
0.14854E 01	44790.	0.40000E-01	510.	26036.32	24732.85	0.78431E-04
0.15254E 01	45300.	0.40000E-01	510.	27759.67	26369.92	0.78431E-04
0.15654E 01	45720.	0.40000E-01	420.	29690.69	28204.46	0.95238E-04
0.16054E 01	45960.	0.40000E-01	240.	31857.49	30262.60	0.16667E-03
0.16454E 01	46080.	0.40000E-01	120.	34290.79	32574.07	0.33333E-03
0.16854E 01	46200.	0.40000E-01	120.	37022.94	35169.44	0.33333E-03
0.17254E 01	46290.	0.40000E-01	90.	40091.40	38084.29	0.44444E-03
0.17654E 01	46380.	0.40000E-01	90.	43533.71	41354.26	0.44444E-03
0.18054E 01	46410.	0.40000E-01	30.	47391.54	45018.95	0.13333E-02

FATIGUE CRACK PROPAGATION DATA

SPEC NO 07210 LONG GRAIN ROOM AIR TEST FREQ 5 HZ

	PMAX 779.	PMIN 39.	AO 0.60540	NO 0.	B 0.24970	W 2.50000
A	N	DELA	DELN	KMAX	DELK	DADN
0.60540E 00	4800.	0.00000E-01	4800.	10778.43	10234.82	0.83333E-05
0.64540E 00	8910.	0.40000E-01	4110.	11034.17	10481.76	0.97324E-05
0.72540E 00	12750.	0.40000E-01	3840.	11334.83	10767.37	0.10417E-04
0.76540E 00	16200.	0.40000E-01	3450.	11678.05	11093.41	0.11594E-04
0.80540E 00	19380.	0.40000E-01	3180.	12061.59	11457.74	0.12579E-04
0.84540E 00	22320.	0.40000E-01	2940.	12443.39	11858.43	0.13605E-04
0.88540E 00	24930.	0.40000E-01	2610.	12941.73	12293.83	0.15326E-04
0.92540E 00	27450.	0.40000E-01	2520.	13435.52	12762.89	0.15873E-04
0.96540E 00	29400.	0.40000E-01	1950.	13944.30	13265.20	0.20511E-04
0.10054E 01	31500.	0.40000E-01	2100.	14528.64	13801.32	0.19047E-04
0.10454E 01	33150.	0.40000E-01	1650.	15130.34	14372.84	0.24242E-04
0.10854E 01	34680.	0.40000E-01	1530.	15772.16	14982.55	0.26144E-04
0.11254E 01	36180.	0.40000E-01	1500.	16458.00	15434.06	0.26667E-04
0.11654E 01	37530.	0.40000E-01	1350.	17193.73	16332.95	0.29630E-04
0.12054E 01	38640.	0.40001E-01	1110.	17986.48	17086.02	0.36037E-04
0.12454E 01	39660.	0.40000E-01	1020.	18845.04	17901.40	0.39214E-04
0.12854E 01	40650.	0.40000E-01	990.	19780.02	18789.76	0.40404E-04
0.13254E 01	41580.	0.40000E-01	930.	20803.90	19762.39	0.43011E-04
0.13654E 01	42330.	0.40000E-01	750.	21931.11	20833.16	0.53333E-04
0.14054E 01	43110.	0.40000E-01	780.	23178.30	22017.91	0.51282E-04
0.14454E 01	43740.	0.40000E-01	630.	24544.16	23334.39	0.63492E-04
0.14854E 01	44280.	0.40000E-01	540.	26109.31	24802.19	0.74074E-04
0.15254E 01	44790.	0.40000E-01	510.	27637.49	26443.85	0.78431E-04
0.15654E 01	45300.	0.40000E-01	510.	29774.13	28283.53	0.78431E-04
0.16054E 01	45720.	0.40000E-01	420.	31944.80	30347.44	0.95234E-04
0.16454E 01	45960.	0.40000E-01	240.	34386.92	32665.39	0.16667E-03
0.16854E 01	46080.	0.40000E-01	120.	37126.73	35268.04	0.33333E-03
0.17254E 01	46200.	0.40000E-01	120.	40203.79	38191.05	0.33333E-03
0.17654E 01	46290.	0.40000E-01	90.	43655.75	41470.19	0.44444E-03
0.18054E 01	46380.	0.40000E-01	90.	47524.39	45145.15	0.44444E-03
0.18454E 01	46410.	0.40000E-01	30.	51853.55	49257.58	0.13333E-02

FATIGUE CRACK PROPAGATION DATA

SPEC NO 0742 LONG GRAIN ROOM SALT TEST F 5 HZ

	P _{MAX} 497.	P _{MIN} 25.	ΔP 0.46790	R _Q 0.	R 0.25330	R 2.50000
A	N	DELA	DELN	KMAX	DELK	DELN
0.68790E 00	6990.	0.40000E-01	6990.	6950.75	6601.12	0.57225E-05
0.72790E 00	12120.	0.40000E-01	5130.	7141.49	6782.27	0.77973E-05
0.76790E 00	16440.	0.40000E-01	4320.	7359.03	6988.86	0.92592E-05
0.80790E 00	19600.	0.40000E-01	3360.	7601.80	7219.42	0.11405E-04
0.84790E 00	22800.	0.40000E-01	3600.	7868.52	7472.73	0.13333E-04
0.88790E 00	25560.	0.40000E-01	2760.	8158.17	7747.81	0.14493E-04
0.92790E 00	27660.	0.40000E-01	2100.	8470.13	8044.07	0.19048E-04
0.96790E 00	29610.	0.40000E-01	1950.	8804.07	8361.22	0.20513E-04
0.10079E 01	31410.	0.40000E-01	1800.	9146.51	8699.73	0.22222E-04
0.10479E 01	32910.	0.40000E-01	1500.	9540.45	9060.54	0.26667E-04
0.10879E 01	34290.	0.40000E-01	1380.	9945.6A	9445.40	0.28985E-04
0.11279E 01	35A50.	0.40000E-01	1500.	10378.86	9856.79	0.25641E-04
0.11679E 01	36870.	0.40000E-01	1020.	10843.77	10298.32	0.39216E-04
0.12079E 01	37890.	0.40000E-01	1020.	11344.69	10774.04	0.39216E-04
0.12479E 01	38640.	0.40000E-01	750.	11887.43	11289.48	0.53333E-04
0.12879E 01	39450.	0.40000E-01	810.	12478.72	11851.03	0.49383E-04
0.13279E 01	40200.	0.40000E-01	750.	13128.46	12466.19	0.53333E-04
0.13679E 01	40860.	0.40000E-01	660.	13839.84	13143.69	0.60606E-04
0.14079E 01	41400.	0.40000E-01	540.	14629.33	13893.46	0.74074E-04
0.14479E 01	41850.	0.40000E-01	450.	15508.79	14726.79	0.88889E-04
0.14879E 01	42300.	0.40000E-01	450.	16485.21	15655.99	0.88889E-04
0.15279E 01	42690.	0.40000E-01	390.	17579.86	16695.57	0.10256E-03
0.15679E 01	42990.	0.40000E-01	300.	18808.55	17860.57	0.13333E-03
0.16079E 01	43290.	0.40000E-01	300.	20183.17	19167.94	0.13333E-03
0.16479E 01	43510.	0.40000E-01	240.	21728.91	20635.93	0.16667E-03
0.16879E 01	43770.	0.40000E-01	240.	23464.86	22284.55	0.16667E-03
0.17279E 01	43980.	0.40000E-01	210.	25413.82	24135.48	0.19048E-03
0.17679E 01	44130.	0.40000E-01	150.	27600.31	26211.99	0.26667E-03
0.18079E 01	44280.	0.40000E-01	150.	30050.99	28539.40	0.26667E-03
0.18479E 01	44400.	0.40000E-01	120.	32792.81	31143.30	0.33333E-03
0.18879E 01	44520.	0.40000E-01	120.	35846.38	34052.77	0.33333E-03
0.19279E 01	44610.	0.40000E-01	90.	39274.42	37298.88	0.44444E-03
0.19679E 01	44670.	0.40000E-01	60.	43078.74	40911.84	0.66667E-03
0.20079E 01	44730.	0.40000E-01	60.	47308.60	44927.04	0.66667E-03
0.20479E 01	44790.	0.40000E-01	60.	51994.97	49379.57	0.66667E-03
0.20879E 01	44850.	0.40000E-01	60.	57184.74	54308.30	0.66667E-03

FATIGUE CRACK PROPAGATION DATA

SPEC NO 0855 LONG GRAIN ROOM AIR TEST FREQ 5 HZ

	P _{MAX} 779.	P _{MIN} 39.	ΔP 0.40760	R _Q 0.	R 0.25510	R 2.50000
A	N	DELA	DELN	KMAX	DELK	DELN
0.64790E 00	5070.	0.40000E-01	5070.	10562.8A	10034.06	0.78494E-05
0.68790E 00	9630.	0.40000E-01	4560.	10815.70	10274.23	0.87719E-05
0.72790E 00	13080.	0.40000E-01	3450.	11112.27	10555.95	0.11504E-04
0.76790E 00	16A00.	0.40000E-01	3720.	11450.45	10877.20	0.10753E-04
0.80790E 00	20220.	0.40000E-01	3420.	11827.9A	11235.84	0.11496E-04
0.84790E 00	23430.	0.40000E-01	3210.	12242.83	11629.91	0.12441E-04
0.88790E 00	26220.	0.40000E-01	2790.	12691.4A	1205A.00	0.14337E-04
0.92790E 00	28A00.	0.40000E-01	25A0.	1317A.54	1251A.8A	0.15504E-04
0.96790E 00	31260.	0.40000E-01	24A0.	1369A.17	13012.39	0.16260E-04
0.10079E 01	33330.	0.40000E-01	2070.	14252.61	13539.07	0.19324E-04
0.10479E 01	35190.	0.40000E-01	18A0.	14843.60	14100.48	0.21505E-04
0.10879E 01	36930.	0.40000E-01	1740.	15473.9A	14690.30	0.22988E-04
0.11279E 01	38500.	0.40000E-01	1570.	16147.90	15339.4A	0.25478E-04
0.11679E 01	401A0.	0.40000E-01	15A0.	16871.00	1602A.3A	0.25316E-04
0.12079E 01	41400.	0.40000E-01	1320.	17650.27	167AA.64	0.30303E-04
0.12479E 01	424A0.	0.40000E-01	10A0.	18494.34	17568.45	0.37037E-04
0.12879E 01	43590.	0.40000E-01	1110.	19414.06	18442.13	0.38038E-04
0.13279E 01	44520.	0.40000E-01	930.	20421.40	19399.04	0.43011E-04
0.13679E 01	453A0.	0.40000E-01	8A0.	21510.82	20452.91	0.47620E-04
0.14079E 01	46140.	0.40000E-01	7A0.	2275A.64	21A10.27	0.51282E-04
0.14479E 01	46770.	0.40000E-01	630.	24123.13	22915.44	0.63492E-04
0.14879E 01	47430.	0.40000E-01	6A0.	25A44.8A	24360.82	0.6A066E-04
0.15279E 01	47790.	0.40000E-01	3A0.	2734A.73	25977.86	0.11111E-03
0.15679E 01	48240.	0.40000E-04	450.	29254.31	277A9.74	0.88889E-04
0.16079E 01	48540.	0.40000E-01	300.	31390.8A	29A23.14	0.13333E-03
0.16479E 01	487A0.	0.40000E-01	240.	3379A.73	3210A.45	0.16667E-03
0.16879E 01	49020.	0.40000E-01	240.	36497.72	34A70.52	0.16667E-03
0.17279E 01	49140.	0.40000E-01	120.	3952A.83	37549.69	0.33333E-03
0.17679E 01	49230.	0.40000E-01	90.	4292A.26	40779.13	0.44444E-03
0.18079E 01	492A0.	0.40000E-01	30.	4673A.5A	4439A.69	0.33333E-03
0.18479E 01	49290.	0.40000E-01	30.	51003.45	48450.04	0.33333E-03
0.18879E 01	49320.	0.40000E-01	30.	557A7.45	52075.73	0.33333E-03

FATIGUE CRACK PROPAGATION DATA

SPEC NO 0856 LONG GRAIN ROOM AIR TEST FREQ 5 HZ

	P _{MAX} 779.	P _{MIN} 39.	ΔU 0.60930	N _D 0.	H 0.25560	n 2.50000
A	N	ΔELA	ΔELN	K _{MAX}	ΔELK	DAWN
0.64930E 00	5550.	0.40000E-01	5550.	10551.98	10023.71	0.72072E-05
0.66930E 00	9900.	0.40000E-01	4350.	10806.25	10265.26	0.91954E-05
0.72930E 00	14160.	0.40000E-01	4260.	11104.05	10548.15	0.93897E-05
0.76930E 00	18000.	0.40000E-01	3840.	11443.29	10870.39	0.10417E-04
0.80930E 00	21630.	0.40000E-01	3630.	11821.73	11229.89	0.11019E-04
0.84930E 00	25050.	0.40000E-01	3420.	12237.23	11624.60	0.11696E-04
0.88930E 00	28020.	0.40000E-01	2970.	12688.42	12053.19	0.13468E-04
0.92930E 00	30750.	0.40000E-01	2730.	13174.22	12514.67	0.14652E-04
0.96930E 00	32910.	0.40000E-01	2160.	13694.16	13008.59	0.18518E-04
0.10093E 01	35310.	0.40000E-01	2400.	14249.00	13535.64	0.16667E-04
0.10493E 01	37140.	0.40000E-01	1830.	14840.47	14097.51	0.21858E-04
0.10893E 01	38910.	0.40000E-01	1770.	15471.39	14696.84	0.22599E-04
0.11293E 01	40590.	0.40000E-01	1680.	16145.96	15337.64	0.23809E-04
0.11693E 01	42090.	0.40000E-01	1500.	16869.85	16025.29	0.26667E-04
0.12093E 01	43650.	0.40000E-01	1580.	17650.13	16766.50	0.25641E-04
0.12493E 01	44640.	0.40000E-01	990.	18495.67	17569.71	0.40404E-04
0.12893E 01	45870.	0.40000E-01	1230.	19416.91	18444.84	0.32520E-04
0.13293E 01	46590.	0.40000E-01	720.	20426.37	19403.75	0.55555E-04
0.13693E 01	47490.	0.40000E-01	900.	21538.26	20459.98	0.44444E-04
0.14093E 01	48150.	0.40000E-01	660.	22769.04	21629.15	0.60606E-04
0.14493E 01	48840.	0.40000E-01	690.	24137.12	22928.73	0.57971E-04
0.14893E 01	49410.	0.40000E-01	570.	25662.90	24378.13	0.70175E-04
0.15293E 01	49890.	0.40000E-01	480.	27369.93	25999.69	0.83333E-04
0.15693E 01	50190.	0.40000E-01	300.	29282.89	27816.89	0.13333E-03
0.16093E 01	50430.	0.40000E-01	240.	31429.80	29856.31	0.16667E-03
0.16493E 01	50580.	0.40000E-01	150.	33840.74	32146.55	0.26667E-03
0.16893E 01	50730.	0.40000E-01	150.	36548.21	34718.48	0.26667E-03
0.17293E 01	50820.	0.40000E-01	90.	39587.78	37605.88	0.44444E-03
0.17693E 01	50910.	0.40001E-01	90.	42997.70	40845.09	0.44444E-03
0.18093E 01	50940.	0.40000E-01	30.	46819.40	44475.46	0.13333E-02
0.18493E 01	51000.	0.40000E-01	60.	51094.75	48536.77	0.66667E-03

FATIGUE CRACK PROPAGATION DATA

SPEC NO 0857 LONG GRAIN ROOM SALT TEST F 5 HZ

	P _{MAX} 497.	P _{MIN} 25.	ΔU 0.64430	N _D 0.	H 0.25400	n 2.50000
A	N	ΔELA	ΔELN	K _{MAX}	ΔELK	DAWN
0.68830E 00	4380.	0.40000E-01	4380.	6933.35	6544.59	0.91324E-05
0.72830E 00	8100.	0.40000E-01	3720.	7124.88	6764.54	0.10743E-04
0.76830E 00	11520.	0.40000E-01	3420.	7341.04	6971.77	0.11494E-04
0.80830E 00	14640.	0.40000E-01	3120.	7581.38	7201.44	0.12421E-04
0.84830E 00	18240.	0.40000E-01	3600.	7849.61	7454.77	0.13111E-04
0.88830E 00	21090.	0.40000E-01	2850.	8138.73	7729.34	0.14035E-04
0.92830E 00	23190.	0.40000E-01	2100.	8440.99	8024.95	0.19046E-04
0.96830E 00	25230.	0.40000E-01	2040.	8783.26	8341.36	0.19666E-04
0.10083E 01	27240.	0.40000E-01	2010.	9138.91	8679.21	0.19900E-04
0.10483E 01	28920.	0.40000E-01	1680.	9514.00	9039.24	0.23409E-04
0.10883E 01	30300.	0.40000E-01	1380.	9922.44	9423.33	0.24985E-04
0.11283E 01	31500.	0.40000E-01	1200.	10350.79	9831.93	0.33333E-04
0.11683E 01	32670.	0.40000E-01	1170.	10818.63	10274.45	0.34184E-04
0.12083E 01	33870.	0.40000E-01	1200.	11318.60	10749.28	0.33333E-04
0.12483E 01	34890.	0.40000E-01	1020.	11860.35	11263.77	0.39218E-04
0.12883E 01	35760.	0.40000E-01	870.	12450.48	11824.21	0.44977E-04
0.13283E 01	36540.	0.40001E-01	780.	13097.06	12438.27	0.51283E-04
0.13683E 01	37170.	0.40000E-01	630.	13809.14	13114.53	0.63402E-04
0.14083E 01	37800.	0.40000E-01	630.	14597.34	13863.08	0.63402E-04
0.14483E 01	38340.	0.40000E-01	540.	15473.30	14694.98	0.74074E-04
0.14883E 01	38850.	0.40000E-01	510.	16450.30	15622.83	0.74431E-04
0.15283E 01	39240.	0.40000E-01	390.	17542.87	16660.45	0.10246E-03
0.15683E 01	39660.	0.40000E-01	420.	18747.81	17821.77	0.95233E-04
0.16083E 01	40020.	0.40000E-01	360.	20142.14	19128.97	0.11111E-03
0.16483E 01	40350.	0.40000E-01	330.	21685.45	20594.68	0.12121E-03
0.16883E 01	40590.	0.40000E-01	240.	23418.61	22240.84	0.16667E-03
0.17283E 01	40800.	0.40000E-01	210.	25364.32	24088.48	0.19046E-03
0.17683E 01	41040.	0.40000E-01	240.	27547.51	26161.84	0.16667E-03
0.18083E 01	41250.	0.40000E-01	210.	29991.84	28485.13	0.19046E-03
0.18483E 01	41400.	0.40000E-01	150.	32731.74	31085.30	0.26667E-03
0.18883E 01	41550.	0.40000E-01	150.	35790.49	33940.20	0.26667E-03
0.19283E 01	41670.	0.40000E-01	120.	39201.83	37229.45	0.33333E-03
0.19683E 01	41790.	0.40000E-01	120.	42999.89	40838.48	0.33333E-03
0.20083E 01	41880.	0.40000E-01	90.	47220.34	44845.11	0.44444E-03
0.20483E 01	41910.	0.40000E-01	30.	51900.81	49240.96	0.13333E-02

FATIGUE CRACK PROPAGATION DATA

SPEC NO 1101 TRANS GRAIN ROOM AIR TEST F 5 HZ

	PMAX SRE.	PMIN 29.	AO 0.04340	NO 0.	R 0.25340	A 2.50000
A	N	DELA	DELN	KMAX	DELK	DALN
0.68390E-00	9490.	0.40000E-01	9990.	8157.57	7753.19	0.40000E-05
0.72390E-00	21840.	0.40000E-01	11850.	8378.81	7983.46	0.33755E-05
0.76390E-00	31620.	0.40000E-01	9780.	8631.63	8203.75	0.40900E-05
0.80390E-00	41760.	0.40000E-01	10140.	8914.38	8472.48	0.39444E-05
0.84390E-00	50010.	0.40000E-01	8250.	9225.46	8768.14	0.48445E-05
0.88390E-00	58350.	0.40000E-01	8340.	9563.62	9089.54	0.47962E-05
0.92390E-00	64320.	0.40000E-01	5970.	9926.00	9435.85	0.67002E-05
0.96390E-00	71340.	0.40000E-01	7020.	10316.41	9806.91	0.56980E-05
0.10039E-01	75990.	0.40000E-01	4650.	10735.06	10202.90	0.86021E-05
0.10439E-01	81090.	0.40000E-01	5100.	11179.23	10625.06	0.78431E-05
0.10839E-01	85410.	0.40000E-01	4320.	11652.94	11075.28	0.92595E-05
0.11239E-01	89050.	0.40000E-01	2640.	12159.23	11556.48	0.15152E-04
0.11639E-01	92070.	0.40000E-01	4020.	12702.24	12072.57	0.99502E-05
0.12039E-01	94800.	0.40000E-01	2730.	13287.14	12628.47	0.14652E-04
0.12439E-01	97500.	0.40000E-01	2700.	13920.46	13230.40	0.14815E-04
0.12839E-01	99240.	0.40000E-01	1740.	14610.05	13885.80	0.22988E-04
0.13239E-01	100950.	0.40000E-01	1710.	15365.09	14603.42	0.23392E-04
0.13639E-01	102720.	0.40000E-01	1770.	16196.17	15393.30	0.22594E-04
0.14039E-01	104920.	0.40000E-01	1200.	17115.50	16267.05	0.33333E-04
0.14439E-01	105150.	0.40000E-01	1230.	18136.93	17237.85	0.32520E-04
0.14839E-01	106050.	0.40000E-01	900.	19275.55	18320.03	0.44444E-04
0.15239E-01	106780.	0.40000E-01	930.	20549.07	19530.42	0.43011E-04
0.15639E-01	107700.	0.40000E-01	720.	21975.70	20886.52	0.55556E-04
0.16039E-01	108270.	0.40000E-01	570.	23576.93	22408.18	0.70175E-04
0.16439E-01	108720.	0.40000E-01	450.	25374.79	24116.91	0.88889E-04
0.16839E-01	109170.	0.40000E-01	450.	27393.24	26035.30	0.88889E-04
0.17239E-01	109410.	0.40000E-01	240.	29660.16	28189.86	0.16667E-03
0.17639E-01	109560.	0.40000E-01	150.	32203.91	30607.50	0.26667E-03
0.18039E-01	109710.	0.40000E-01	150.	35054.57	33316.86	0.26667E-03
0.18439E-01	109800.	0.40000E-01	90.	38244.23	36348.40	0.44444E-03
0.18839E-01	109860.	0.40000E-01	60.	41810.33	39737.71	0.66667E-03
0.19239E-01	109890.	0.40000E-01	30.	45787.79	43518.00	0.13333E-02

FATIGUE CRACK PROPAGATION DATA

SPEC NO 1102 TRANS GRAIN ROOM SALT TEST F 5 HZ

	PMAX SRE.	PMIN 23.	AO 0.68800	NO 0.	R 0.25340	A 2.50000
A	N	DELA	DELN	KMAX	DELK	DALN
0.72800E-00	4690.	0.40000E-01	4690.	6708.27	6377.88	0.81000E-05
0.76800E-00	9720.	0.40000E-01	4830.	6912.59	6572.15	0.82818E-05
0.80800E-00	13920.	0.40000E-01	4200.	7148.69	6789.01	0.95238E-05
0.84800E-00	17820.	0.40000E-01	3900.	7391.27	7027.25	0.10256E-04
0.88800E-00	21150.	0.40000E-01	3330.	7663.42	7285.99	0.12012E-04
0.92800E-00	23880.	0.40000E-01	2730.	7956.43	7564.57	0.14652E-04
0.96800E-00	26190.	0.40000E-01	2310.	8270.20	7862.89	0.17318E-04
0.10080E-01	28380.	0.40000E-01	2190.	8605.04	8181.24	0.18264E-04
0.10480E-01	30150.	0.40000E-01	1770.	8961.97	8520.59	0.22599E-04
0.10880E-01	31800.	0.40000E-01	1650.	9342.61	8882.49	0.26242E-04
0.11280E-01	33270.	0.40000E-01	1470.	9749.59	9269.42	0.27211E-04
0.11680E-01	34560.	0.40000E-01	1290.	10188.33	9684.65	0.31008E-04
0.12080E-01	35520.	0.40000E-01	960.	10658.96	10132.10	0.41667E-04
0.12480E-01	36450.	0.40000E-01	930.	11166.81	10616.84	0.43011E-04
0.12880E-01	37260.	0.40000E-01	810.	11722.32	11144.99	0.49383E-04
0.13280E-01	38010.	0.40000E-01	750.	12338.91	11723.61	0.53333E-04
0.13680E-01	38640.	0.40000E-01	630.	13001.04	12360.73	0.63492E-04
0.14080E-01	39300.	0.40000E-01	600.	13742.78	13065.99	0.60000E-04
0.14480E-01	39810.	0.40000E-01	510.	14567.21	13849.77	0.78431E-04
0.14880E-01	40260.	0.40000E-01	450.	15486.35	14723.64	0.88889E-04
0.15280E-01	40680.	0.40000E-01	420.	16514.95	15701.58	0.95238E-04
0.15680E-01	41040.	0.40000E-01	360.	17667.47	16797.34	0.11111E-03
0.16080E-01	41460.	0.40000E-01	420.	18960.65	18028.83	0.95238E-04
0.16480E-01	41730.	0.40000E-01	270.	20413.19	19407.84	0.14815E-03
0.16880E-01	41970.	0.40000E-01	240.	22043.76	20958.18	0.16667E-03
0.17280E-01	42210.	0.40000E-01	240.	23875.22	22699.30	0.16667E-03
0.17680E-01	42420.	0.40000E-01	210.	25929.48	24652.45	0.19048E-03
0.18080E-01	42540.	0.40000E-01	120.	29481.69	28031.61	0.50000E-03
0.18480E-01	42660.	0.40000E-01	120.	32207.54	30821.31	0.33333E-03
0.18880E-01	42750.	0.20000E-01	90.	33688.42	32027.35	0.22222E-03

FATIGUE CRACK PROPAGATION DATA

SPEC NO 1204 LONG GRAIN ROOM AIR TEST FREQ 5 HZ

	PMAX 779.	PMIN 39.	AO 0.00730	NO 0.	B 0.24930	N 2.50000
A	N	DELA	DELN	KMAX	DELK	DADN
0.64730E 00	8880.	0.40000E-01	8880.	10806.84	10265.82	0.45045E-05
0.68730E 00	14370.	0.40000E-01	5490.	11065.21	10511.25	0.72860E-05
0.72730E 00	20550.	0.40000E-01	6180.	11368.36	10799.23	0.64725E-05
0.76730E 00	26940.	0.40000E-01	6390.	11714.13	11127.68	0.62598E-05
0.80730E 00	32940.	0.40000E-01	6000.	12100.15	11494.38	0.60667E-05
0.84730E 00	37650.	0.40000E-01	4710.	12524.41	11897.39	0.84926E-05
0.88730E 00	42180.	0.40000E-01	4530.	12985.12	12335.04	0.88300E-05
0.92730E 00	46230.	0.40000E-01	4050.	13461.36	12806.43	0.98765E-05
0.96730E 00	49650.	0.40000E-01	3420.	14012.75	13311.23	0.11696E-04
0.10073E 01	52590.	0.40000E-01	2940.	14579.80	13849.88	0.13606E-04
0.10473E 01	55320.	0.40000E-01	2730.	15184.20	14424.03	0.14652E-04
0.10873E 01	57930.	0.40000E-01	2610.	15829.01	15036.56	0.15326E-04
0.11273E 01	60180.	0.40000E-01	2250.	16518.27	15691.31	0.17778E-04
0.11673E 01	62070.	0.40000E-01	1890.	17257.78	16393.79	0.21164E-04
0.12073E 01	63420.	0.40000E-01	1350.	18054.69	17150.81	0.29630E-04
0.12473E 01	64950.	0.40000E-01	1530.	18917.86	17970.77	0.26144E-04
0.12873E 01	66390.	0.40000E-01	1440.	19858.41	18864.23	0.27778E-04
0.13273E 01	67410.	0.40000E-01	1020.	20880.39	19842.65	0.39216E-04
0.13673E 01	68370.	0.40000E-01	960.	22022.87	20920.33	0.41667E-04
0.14073E 01	69240.	0.40000E-01	870.	23276.15	22112.77	0.45977E-04
0.14473E 01	69990.	0.40000E-01	750.	24673.34	23438.11	0.53333E-04
0.14873E 01	70740.	0.40000E-01	750.	26229.30	24916.18	0.53333E-04
0.15273E 01	71250.	0.40000E-01	510.	27969.12	26568.89	0.78631E-04
0.15673E 01	71640.	0.40000E-01	390.	29919.30	28421.44	0.10256E-03
0.16073E 01	71970.	0.40000E-01	330.	32107.71	30500.29	0.12121E-03
0.16473E 01	72000.	0.40000E-01	30.	34565.13	32834.68	0.13333E-02
0.16873E 01	72510.	0.40000E-01	510.	37325.61	35456.96	0.78431E-04
0.17273E 01	72720.	0.40000E-01	210.	40423.66	38399.91	0.19048E-03
0.17673E 01	72870.	0.40000E-01	150.	43899.97	41702.19	0.26667E-03
0.18073E 01	72990.	0.40000E-01	120.	47796.05	45403.21	0.33333E-03
0.18473E 01	73050.	0.40000E-01	60.	52154.83	49543.78	0.66667E-03
0.18873E 01	73080.	0.40000E-01	30.	57026.49	54171.55	0.13333E-02
0.19273E 01	73110.	0.40001E-01	30.	62459.77	59332.82	0.13334E-02

FATIGUE CRACK PROPAGATION DATA

SPEC NO 1205 LONG GRAIN ROOM SALT TEST F 5 HZ

	PMAX 497.	PMIN 25.	AO 0.04810	NO 0.	B 0.25220	N 2.50000
A	N	DELA	DELN	KMAX	DELK	DADN
0.68810E 00	5610.	0.40000E-01	5610.	6981.93	6630.73	0.71301E-05
0.72810E 00	9660.	0.40000E-01	4050.	7173.68	6812.84	0.98765E-05
0.76810E 00	13290.	0.40000E-01	3630.	7392.25	7020.41	0.11019E-04
0.80810E 00	16680.	0.40000E-01	3390.	7636.23	7252.12	0.11799E-04
0.84810E 00	19080.	0.40000E-01	2400.	7904.23	7506.64	0.16667E-04
0.88810E 00	21420.	0.40000E-01	2340.	8195.29	7783.06	0.17094E-04
0.92810E 00	23940.	0.40000E-01	2520.	8508.63	8080.64	0.15873E-04

FATIGUE CRACK PROPAGATION DATA

SPEC NO 1320 LONG GRAIN ROOM AIR TEST FREQ 5 HZ

	P _{MAX} 779.	P _{MIN} 39.	A _D 0.60960	N _D 0.	B 0.25420	W 2.50000
A	N	DELA	DELN	K _{MAX}	DELK	DADN
0.64860E 00	3810.	0.40000E-01	3810.	10606.07	10075.09	0.10499F-04
0.68860E 00	8070.	0.40000E-01	4260.	10860.86	10317.13	0.03897F-05
0.72860E 00	12240.	0.40000E-01	4170.	11159.63	10600.94	0.05923F-05
0.76860E 00	16320.	0.40000E-01	4080.	11499.94	10924.25	0.08039E-05
0.80860E 00	19950.	0.40000E-01	3630.	11879.86	11285.11	0.11019E-04
0.84860E 00	23160.	0.40000E-01	3210.	12297.06	11681.43	0.12461F-04
0.88860E 00	25710.	0.40000E-01	2550.	12750.17	12111.85	0.15686E-04
0.92860E 00	28560.	0.40000E-01	2850.	13217.93	12575.20	0.14035E-04
0.96860E 00	30840.	0.40000E-01	2280.	13740.12	13071.24	0.17544E-04
0.10086E 01	32910.	0.40000E-01	2070.	14317.45	13600.67	0.19324E-04
0.10486E 01	34710.	0.40000E-01	1800.	14911.47	14164.95	0.22277E-04
0.10886E 01	36540.	0.40000E-01	1830.	15545.13	14766.89	0.21858E-04
0.11286E 01	38070.	0.40000E-01	1530.	16222.58	15410.43	0.26144E-04
0.11686E 01	39720.	0.40000E-01	1650.	16949.45	16100.91	0.24242E-04
0.12086E 01	40920.	0.40000E-01	1200.	17733.05	16845.27	0.33333E-04
0.12486E 01	41910.	0.40000E-01	990.	18581.86	17651.59	0.40404E-04
0.12886E 01	42900.	0.40000E-01	990.	19506.88	18530.29	0.40404E-04
0.13286E 01	43830.	0.40000E-01	930.	20520.20	19492.89	0.43011E-04
0.13686E 01	44730.	0.40000E-01	900.	21636.36	20553.17	0.44444E-04
0.14086E 01	45540.	0.40000E-01	810.	22871.64	21726.61	0.49383E-04
0.14486E 01	46260.	0.40000E-01	720.	24244.71	23030.93	0.55556E-04
0.14886E 01	46740.	0.40000E-01	480.	25776.12	24485.68	0.83333E-04
0.15286E 01	47310.	0.40000E-01	570.	27488.78	26112.60	0.70175E-04
0.15686E 01	47820.	0.40000E-01	510.	29408.47	27936.18	0.78431E-04
0.16086E 01	48180.	0.40000E-01	360.	31563.00	29982.45	0.11111E-03
0.16486E 01	48540.	0.40000E-01	360.	33982.04	32280.79	0.11111E-03
0.16886E 01	48810.	0.40000E-01	270.	36698.87	34861.60	0.14815E-03
0.17286E 01	49050.	0.40000E-01	240.	39748.55	37758.61	0.16667E-03
0.17686E 01	49230.	0.40000E-01	180.	43171.11	41009.81	0.22233E-03
0.18086E 01	49410.	0.40000E-01	180.	47005.80	44652.53	0.22222E-03
0.18486E 01	49500.	0.40000E-01	90.	51297.13	48729.02	0.44444E-03
0.18886E 01	49560.	0.40000E-01	60.	56091.45	53283.31	0.66667E-03
0.19286E 01	49590.	0.40000E-01	30.	61439.39	58361.52	0.13333E-02
0.19686E 01	49620.	0.40000E-01	30.	67392.06	64018.19	0.13333E-02

FATIGUE CRACK PROPAGATION DATA

SPEC NO 1321 LONG GRAIN ROOM AIR TEST FREQ 5 HZ

	P _{MAX} 621.	P _{MIN} 31.	A _D 0.60100	N _D 0.	B 0.24930	W 2.50000
A	N	DELA	DELN	K _{MAX}	DELK	DADN
0.64100E 00	9840.	0.40000E-01	9840.	8585.89	8157.30	0.40650E-05
0.68100E 00	17850.	0.40000E-01	8010.	8786.05	8347.46	0.49938E-05
0.72100E 00	24480.	0.40000E-01	6630.	9022.25	8571.88	0.60332E-05
0.76100E 00	30840.	0.40000E-01	6360.	9292.60	8828.73	0.62893E-05
0.80100E 00	37890.	0.40000E-01	7050.	9595.42	9116.43	0.56738E-05
0.84100E 00	42390.	0.40000E-01	4500.	9928.89	9433.25	0.88889E-05
0.88100E 00	46890.	0.40000E-01	4500.	10291.71	9777.96	0.88889E-05
0.92100E 00	51600.	0.40000E-01	4710.	10682.90	10149.62	0.84926E-05
0.96100E 00	55470.	0.40000E-01	3870.	11101.97	10547.78	0.10336E-04
0.10010E 01	59010.	0.40000E-01	3540.	11549.56	10973.02	0.11300E-04
0.10410E 01	62040.	0.40000E-01	3030.	12026.57	11426.21	0.13201E-04
0.10810E 01	64740.	0.40000E-01	2700.	12535.29	11909.54	0.14815E-04
0.11210E 01	67140.	0.40000E-01	2400.	13078.88	12426.00	0.16667E-04
0.11610E 01	69360.	0.40000E-01	2220.	13661.73	12979.76	0.18018E-04
0.12010E 01	71250.	0.40000E-01	1890.	14289.38	13576.07	0.21164E-04
0.12410E 01	72960.	0.40000E-01	1710.	14968.67	14221.45	0.23392E-04
0.12810E 01	74520.	0.40000E-01	1560.	15708.02	14923.89	0.25641E-04
0.13210E 01	76020.	0.40000E-01	1500.	16517.23	15692.71	0.26667E-04
0.13610E 01	77400.	0.40000E-01	1380.	17407.56	16538.60	0.28985E-04
0.14010E 01	78480.	0.40000E-01	1080.	18392.21	17474.09	0.37037E-04
0.14410E 01	79320.	0.40000E-01	840.	19485.75	18513.04	0.47619E-04
0.14810E 01	80250.	0.40000E-01	930.	20704.63	19671.08	0.43011E-04
0.15210E 01	81060.	0.40000E-01	810.	22067.24	20965.67	0.49383E-04
0.15610E 01	81750.	0.40000E-01	690.	23594.04	22416.25	0.57971E-04
0.16010E 01	82380.	0.40000E-01	630.	25307.38	24044.07	0.63492E-04
0.16410E 01	82890.	0.40000E-01	510.	27230.70	25871.38	0.78431E-04
0.16810E 01	83280.	0.40000E-01	390.	29390.58	27923.43	0.10256E-03
0.17210E 01	83610.	0.40000E-01	330.	31816.30	30228.06	0.12121E-03
0.17610E 01	83940.	0.40000E-01	330.	34338.30	32814.18	0.12121E-03
0.18010E 01	84240.	0.40000E-01	300.	37589.15	35712.75	0.13333E-03
0.18410E 01	84420.	0.40000E-01	180.	41003.10	38956.27	0.22222E-03
0.18810E 01	84540.	0.40000E-01	120.	44819.75	42582.39	0.33333E-03
0.19210E 01	84660.	0.40000E-01	120.	49077.94	46628.03	0.33333E-03
0.19610E 01	84720.	0.40000E-01	60.	53820.00	51133.37	0.66668E-03
0.20010E 01	84750.	0.40000E-01	30.	59890.93	56141.17	0.13333E-02

FATIGUE CRACK PROPAGATION DATA

SPEC NO 1322 LONG GRAIN ROOM SALT TEST F 5 HZ

	P _{MAX} 497.	P _{MIN} 25.	A _O 0.72820	N _O 0.	B 0.25390	N 2.50000
A	N	DELA	DELN	KMAX	DELK	DADN
0.76820E 00	2610.	0.40000E-01	2610.	7343.34	6973.96	0.15326E-04
0.80820E 00	4890.	0.40000E-01	2280.	7585.74	7204.17	0.17544E-04
0.84820E 00	6660.	0.40000E-01	1770.	7852.00	7497.04	0.22599E-04
0.88820E 00	8250.	0.40000E-01	1590.	8141.14	7731.64	0.25157E-04
0.92820E 00	9900.	0.40000E-01	1450.	8452.51	8027.34	0.24242E-04
0.96820E 00	11460.	0.40000E-01	1560.	8785.82	8343.88	0.25641E-04
0.10082E 01	12960.	0.40000E-01	1500.	9141.64	8681.81	0.26666E-04
0.10482E 01	14130.	0.40000E-01	1170.	9520.79	9041.89	0.34188E-04
0.10882E 01	15240.	0.40000E-01	1110.	9925.26	9426.01	0.36036E-04
0.11282E 01	16290.	0.40000E-01	1050.	10357.70	9836.70	0.38095E-04
0.11682E 01	17250.	0.40000E-01	960.	10821.68	10277.34	0.41667E-04
0.12082E 01	18060.	0.40001E-01	810.	11321.79	10752.30	0.49384E-04
0.12482E 01	18690.	0.40000E-01	630.	11863.61	11266.86	0.63492E-04
0.12882E 01	19500.	0.40000E-01	810.	12453.90	11827.66	0.49383E-04
0.13282E 01	20670.	0.40000E-01	570.	13100.56	12461.59	0.70175E-04
0.13682E 01	20670.	0.40000E-01	600.	13812.77	13117.97	0.66667E-04
0.14082E 01	21210.	0.40000E-01	540.	14600.97	13866.53	0.74074E-04
0.14482E 01	21600.	0.40000E-01	390.	15477.04	14698.53	0.10256E-03
0.14882E 01	21990.	0.40000E-01	390.	16454.02	15626.37	0.10256E-03
0.15282E 01	22320.	0.40000E-01	330.	17546.84	16664.21	0.12121E-03
0.15682E 01	22650.	0.40000E-01	330.	18771.94	17827.70	0.12121E-03
0.16082E 01	22920.	0.40000E-01	270.	20146.26	19132.89	0.14815E-03
0.16482E 01	23130.	0.40000E-01	210.	21689.80	20598.79	0.19048E-03
0.16882E 01	23310.	0.40000E-01	180.	23423.01	22244.81	0.22222E-03
0.17282E 01	23580.	0.40000E-01	270.	25369.18	24093.89	0.14815E-03
0.17682E 01	24060.	0.40000E-01	480.	27532.62	26166.70	0.83333E-04
0.18082E 01	24450.	0.40000E-01	390.	29999.02	28490.04	0.10256E-03
0.18482E 01	24870.	0.40000E-01	420.	32737.08	31090.38	0.95238E-04
0.18882E 01	25200.	0.40000E-01	330.	35796.13	33995.55	0.12121E-03
0.19282E 01	25470.	0.40000E-01	270.	39208.21	37236.00	0.14815E-03
0.19682E 01	25650.	0.40000E-01	180.	43006.87	40843.58	0.22222E-03
0.20082E 01	25830.	0.40000E-01	180.	47227.76	44652.16	0.22222E-03

FATIGUE CRACK PROPAGATION DATA

SPEC NO 1455 LONG GRAIN ROOM AIR TEST FREQ 5 HZ

	P _{MAX} 779.	P _{MIN} 39.	A _O 0.60720	N _O 0.	B 0.25460	N 2.50000
A	N	DELA	DELN	KMAX	DELK	DADN
0.64720E 00	4740.	0.40000E-01	4740.	10581.29	10051.55	0.84388E-05
0.68720E 00	8940.	0.40000E-01	4200.	10834.18	10291.78	0.95238E-05
0.72720E 00	12900.	0.40000E-01	3960.	11130.91	10573.66	0.10161E-04
0.76720E 00	16890.	0.40000E-01	3990.	11469.36	10895.17	0.10025E-04
0.80720E 00	20370.	0.40000E-01	3480.	11847.29	11254.17	0.11494E-04
0.84720E 00	23310.	0.40000E-01	2940.	12262.62	11648.71	0.13605E-04
0.88720E 00	26100.	0.40000E-01	2790.	12713.68	12077.20	0.14337E-04
0.92720E 00	28500.	0.40000E-01	2400.	13199.47	12538.66	0.16667E-04
0.96720E 00	30750.	0.40000E-01	2250.	13719.72	13032.87	0.17778E-04
0.10072E 01	32760.	0.40000E-01	2010.	14274.87	13560.22	0.19961E-04
0.10472E 01	34680.	0.40000E-01	1920.	14866.67	14122.39	0.20833E-04
0.10872E 01	36480.	0.40000E-01	1800.	15497.88	14722.00	0.22222E-04
0.11272E 01	38070.	0.40000E-01	1590.	16172.59	15362.93	0.25157E-04
0.11672E 01	39570.	0.40000E-01	1500.	16896.60	16050.70	0.26667E-04
0.12072E 01	40920.	0.40000E-01	1350.	17676.81	16791.85	0.29630E-04
0.12472E 01	42090.	0.40000E-01	1170.	18521.92	17594.65	0.34188E-04
0.12872E 01	43200.	0.40000E-01	1110.	19442.51	18469.15	0.36036E-04
0.13272E 01	44070.	0.40000E-01	870.	20450.88	19427.04	0.45977E-04
0.13672E 01	44940.	0.40000E-01	870.	21561.47	20462.03	0.45977E-04
0.14072E 01	45810.	0.40000E-01	870.	22790.29	21649.33	0.45977E-04
0.14472E 01	46470.	0.40000E-01	660.	24156.06	22946.73	0.60006E-04
0.14872E 01	47100.	0.40000E-01	630.	25678.83	24393.26	0.63492E-04
0.15272E 01	47550.	0.40000E-01	450.	27382.64	26011.77	0.88889E-04
0.15672E 01	48090.	0.40000E-01	540.	29291.72	27825.27	0.74074E-04
0.16072E 01	48420.	0.40000E-01	330.	31433.77	29860.09	0.12121E-03
0.16472E 01	48690.	0.40000E-01	270.	33839.39	32145.27	0.14815E-03
0.16872E 01	49020.	0.40000E-01	330.	36541.05	34711.68	0.12121E-03
0.17272E 01	49200.	0.40000E-01	180.	39573.66	37592.66	0.22222E-03
0.17672E 01	49290.	0.40001E-01	90.	42976.66	40825.10	0.44445E-03
0.18072E 01	49530.	0.40000E-01	240.	46790.69	44448.18	0.16667E-03
0.18472E 01	49560.	0.40000E-01	30.	51058.73	48502.55	0.13333E-02
0.18872E 01	49590.	0.40000E-01	30.	55826.62	53031.75	0.13333E-02

FATIGUE CRACK PROPAGATION DATA

SPEC NO 1456 LONG GRAIN ROOM AIR TEST FREQ 5 HZ

PMAK 779.		PMIN 39.	AO 0.00910	NO 0.	B 0.25520	W 2.50000
A	N	DELA	DELN	KMAX	DELK	DADN
0.64910E 00	4380.	0.40000E-01	4380.	10567.41	10038.37	0.91324E-05
0.68910E 00	8820.	0.40000E-01	4440.	10821.79	10280.02	0.90090E-05
0.72910E 00	13230.	0.40000E-01	4410.	11119.88	10563.18	0.90703E-05
0.76910E 00	17010.	0.40000E-01	3780.	11459.42	10885.73	0.10582E-04
0.80910E 00	20730.	0.40000E-01	3720.	11838.26	11245.59	0.10753E-04
0.84910E 00	23940.	0.40000E-01	3210.	12254.38	11640.89	0.12461E-04
0.88910E 00	27120.	0.40000E-01	3180.	12706.07	12069.96	0.12579E-04
0.92910E 00	29440.	0.40000E-01	2340.	13192.30	12531.85	0.17094E-04
0.96910E 00	32010.	0.40000E-01	2550.	13712.92	13026.40	0.15686E-04
0.10091E 01	34080.	0.40000E-01	2070.	14268.50	13554.17	0.19324E-04
0.10491E 01	36060.	0.40000E-01	1980.	14860.64	14116.66	0.20202E-04
0.10891E 01	38100.	0.40000E-01	2040.	15492.37	14716.77	0.19608E-04
0.11291E 01	39750.	0.40000E-01	1650.	16167.73	15358.32	0.24242E-04
0.11691E 01	41310.	0.40000E-01	1560.	16892.55	16046.85	0.25641E-04
0.12091E 01	42480.	0.40000E-01	1170.	17673.69	16788.89	0.34188E-04
0.12491E 01	43560.	0.40000E-01	1080.	18520.18	17592.99	0.37037E-04
0.12891E 01	44700.	0.40000E-01	1140.	19442.43	18469.07	0.35088E-04
0.13291E 01	45750.	0.40000E-01	1050.	20453.05	19429.10	0.38095E-04
0.13691E 01	46680.	0.40000E-01	930.	21566.18	20486.51	0.43011E-04
0.14091E 01	47430.	0.40000E-01	750.	22798.16	21656.80	0.53333E-04
0.14491E 01	48090.	0.40000E-01	660.	24167.64	22957.73	0.60606E-04
0.14891E 01	48780.	0.40001E-01	690.	25695.31	24408.92	0.57972E-04
0.15291E 01	49200.	0.40000E-01	420.	27403.83	26031.90	0.95238E-04
0.15691E 01	49620.	0.40000E-01	420.	29318.76	27850.96	0.95238E-04
0.16091E 01	49980.	0.40000E-01	360.	31467.50	29892.13	0.11111E-03
0.16491E 01	50250.	0.40000E-01	270.	33880.93	32184.73	0.14815E-03
0.16891E 01	50460.	0.40000E-01	210.	36591.35	34759.46	0.19048E-03
0.17291E 01	50640.	0.40000E-01	180.	39633.80	37644.59	0.22222E-03
0.17691E 01	50790.	0.40000E-01	150.	43047.65	40892.54	0.26667E-03
0.18091E 01	50880.	0.40000E-01	90.	46872.04	44525.46	0.44444E-03
0.18491E 01	50910.	0.40000E-01	30.	51152.20	48591.34	0.13333E-02
0.18891E 01	50940.	0.40000E-01	30.	55934.80	53134.51	0.13333E-02
0.19291E 01	50970.	0.40000E-01	30.	61268.39	58201.08	0.13333E-02
0.19691E 01	51000.	0.40000E-01	30.	67206.19	63841.64	0.13333E-02

FATIGUE CRACK PROPAGATION DATA

SPEC NO 1457 LONG GRAIN ROOM SALT TEST F 5 HZ

PMAK 497.		PMIN 25.	AO 0.64880	NO 0.	B 0.25300	W 2.50000
A	N	DELA	DELN	KMAX	DELK	DADN
0.68800E 00	9450.	0.40000E-01	9450.	6962.95	6612.71	0.42328E-05
0.72800E 00	15300.	0.40000E-01	5850.	7154.59	6794.71	0.68376E-05
0.76800E 00	19170.	0.40000E-01	3870.	7372.95	7002.08	0.10336E-04
0.80800E 00	22800.	0.40000E-01	3630.	7616.52	7233.40	0.11019E-04
0.84800E 00	25620.	0.40000E-01	2820.	7884.13	7487.55	0.14184E-04
0.88800E 00	28000.	0.40000E-01	2460.	8174.61	7763.42	0.16260E-04
0.92800E 00	30120.	0.40000E-01	2040.	8487.39	8060.47	0.19608E-04
0.96800E 00	32100.	0.40000E-01	1980.	8822.26	8378.50	0.20202E-04
0.10080E 01	33930.	0.40000E-01	1830.	9179.64	8717.89	0.21858E-04
0.10480E 01	35400.	0.40001E-01	1470.	9560.57	9079.67	0.27211E-04
0.10880E 01	36750.	0.40000E-01	1350.	9966.87	9465.53	0.29630E-04
0.11280E 01	38070.	0.40000E-01	1320.	10401.31	9876.11	0.30303E-04
0.11680E 01	39330.	0.40000E-01	1260.	10867.48	10320.84	0.31746E-04
0.12080E 01	40290.	0.40000E-01	960.	11369.89	10797.98	0.41667E-04
0.12480E 01	41100.	0.40000E-01	810.	11914.30	11315.00	0.49383E-04
0.12880E 01	41940.	0.40000E-01	840.	12507.45	11878.32	0.47619E-04
0.13280E 01	42690.	0.40000E-01	750.	13157.30	12495.48	0.53333E-04
0.13680E 01	43200.	0.40000E-01	510.	13873.16	13175.33	0.78431E-04
0.14080E 01	43800.	0.40000E-01	600.	14665.48	13927.80	0.66667E-04
0.14480E 01	44310.	0.40000E-01	510.	15546.09	14764.11	0.78431E-04
0.14880E 01	44760.	0.40000E-01	450.	16528.25	15696.86	0.88889E-04
0.15280E 01	45090.	0.40000E-01	330.	17626.69	16740.05	0.12121E-03
0.15680E 01	45420.	0.40000E-01	330.	18858.32	17909.73	0.12121E-03
0.16080E 01	45690.	0.40000E-01	270.	20239.86	19221.70	0.14815E-03
0.16480E 01	46050.	0.40000E-01	360.	21791.53	20695.39	0.11111E-03
0.16880E 01	46290.	0.40000E-01	240.	23534.23	22350.44	0.16667E-03
0.17280E 01	46500.	0.40000E-01	210.	25490.67	24208.46	0.19048E-03
0.17680E 01	46650.	0.40000E-01	150.	27685.52	26292.91	0.26667E-03
0.18080E 01	46830.	0.40000E-01	180.	30144.55	28620.26	0.22222E-03
0.18480E 01	46980.	0.40000E-01	150.	32897.21	31242.45	0.26667E-03
0.18880E 01	47070.	0.40000E-01	90.	35972.00	34162.58	0.44444E-03
0.19280E 01	47160.	0.40000E-01	90.	39401.98	37420.02	0.44444E-03
0.19680E 01	47229.	0.40000E-01	69.	43219.91	41045.91	0.57971E-03
0.20080E 01	47310.	0.40000E-01	47	47462.79	45075.37	0.49383E-03

FATIGUE CRACK PROPAGATION DATA

SPEC NO 1701 TRANS GRAIN ROOM AIR TEST F 5 HZ

	PMAX 545.	PMIN 29.	AO 0.64830	NO 0.	B 0.25370	W 2.50000
A	N	DELA	DELN	KMAX	DELK	DADN
0.69830E 00	7140.	0.40000E-01	7140.	8170.63	7765.60	0.56022E-05
0.72830E 00	12990.	0.40000E-01	5850.	8345.16	7979.00	0.68376E-05
0.76830E 00	18990.	0.40000E-01	6000.	8651.07	8222.22	0.66667E-05
0.80830E 00	24690.	0.40000E-01	5700.	8936.66	8493.66	0.70175E-05
0.84830E 00	29640.	0.40000E-01	4950.	9250.41	8791.85	0.80808E-05
0.88830E 00	35220.	0.40000E-01	5580.	9591.12	9115.67	0.71685E-05
0.92830E 00	40470.	0.40000E-01	5250.	9957.94	9464.30	0.76191E-05
0.96830E 00	43200.	0.40000E-01	2730.	10350.68	9837.57	0.14652E-04
0.10083E 01	46620.	0.40000E-01	3420.	10769.78	10235.91	0.11696E-04
0.10483E 01	49530.	0.40000E-01	2910.	11216.53	10660.51	0.13746E-04
0.10883E 01	51780.	0.40000E-01	2250.	11693.14	11113.49	0.17778E-04
0.11283E 01	54330.	0.40000E-01	2550.	12202.64	11597.74	0.15686E-04
0.11683E 01	56640.	0.40000E-01	2310.	12749.26	12117.26	0.17316E-04
0.12083E 01	58650.	0.40000E-01	2010.	13338.45	12677.24	0.19900E-04
0.12483E 01	60060.	0.40000E-01	1410.	13976.88	13284.02	0.28369E-04
0.12883E 01	61630.	0.40000E-01	1620.	14672.33	13945.00	0.24691E-04
0.13283E 01	63030.	0.40001E-01	1350.	15434.29	14669.18	0.29630E-04
0.13683E 01	64050.	0.40000E-01	1020.	16273.44	15466.74	0.39216E-04
0.14083E 01	65070.	0.40000E-01	1020.	17202.29	16349.55	0.39216E-04
0.14483E 01	65970.	0.40000E-01	900.	18234.59	17330.66	0.44444E-04
0.14883E 01	66900.	0.40000E-01	930.	19385.92	18424.93	0.43011E-04
0.15283E 01	67440.	0.40000E-01	540.	20673.47	19648.65	0.74074E-04
0.15683E 01	68070.	0.40000E-01	630.	22117.01	21020.63	0.63492E-04
0.16083E 01	68460.	0.40000E-01	390.	23736.59	22559.93	0.10256E-03
0.16483E 01	68820.	0.40000E-01	360.	25555.32	24288.49	0.11111E-03
0.16883E 01	69090.	0.40000E-01	270.	27597.77	26229.70	0.14815E-03
0.17283E 01	69310.	0.40000E-01	210.	29890.70	28408.96	0.19048E-03
0.17683E 01	69420.	0.40000E-01	120.	32463.48	30854.21	0.33333E-03
0.18083E 01	69540.	0.40000E-01	120.	35346.38	33594.20	0.33333E-03
0.18483E 01	69600.	0.40000E-01	60.	38572.86	36660.73	0.66667E-03
0.18883E 01	69690.	0.40000E-01	90.	42177.46	40086.65	0.44444E-03
0.19283E 01	69720.	0.40000E-01	30.	46197.57	43907.47	0.13333E-02

FATIGUE CRACK PROPAGATION DATA

SPEC NO 1702 TRANS GRAIN ROOM SALT TEST F 5 HZ

	PMAX 467.	PMIN 23.	AO 0.64640	NO 0.	B 0.25050	W 2.50000
A	N	DELA	DELN	KMAX	DELK	DADN
0.68640E 00	6780.	0.40000E-01	6780.	6597.90	6272.95	0.58997E-05
0.72640E 00	13630.	0.40000E-01	7050.	6778.16	6444.34	0.56730E-05
0.76640E 00	19950.	0.40000E-01	6120.	6983.89	6639.94	0.65359E-05
0.80640E 00	26490.	0.40000E-01	6540.	7213.71	6858.44	0.61162E-05
0.84640E 00	31740.	0.40000E-01	5250.	7466.27	7098.56	0.76191E-05
0.88640E 00	35970.	0.40000E-01	4230.	7740.73	7359.50	0.96563E-05
0.92640E 00	40170.	0.40000E-01	4200.	8036.29	7640.50	0.95238E-05
0.96640E 00	43410.	0.40000E-01	3240.	8352.86	7941.48	0.12346E-04
0.10064E 01	46410.	0.40000E-01	3000.	8690.68	8262.66	0.13333E-04
0.10464E 01	48510.	0.40000E-01	2100.	9050.77	8605.02	0.19048E-04
0.10864E 01	50400.	0.40000E-01	1890.	9434.90	8970.23	0.21164E-04
0.11264E 01	52050.	0.40000E-01	1650.	9845.44	9360.55	0.24242E-04
0.11664E 01	53550.	0.40000E-01	1500.	10289.90	9779.32	0.26667E-04
0.12064E 01	54750.	0.40000E-01	1200.	10760.60	10230.64	0.33333E-04
0.12464E 01	55800.	0.40000E-01	1050.	11274.68	10719.40	0.38095E-04
0.12864E 01	56820.	0.40000E-01	1020.	11834.58	11251.73	0.39216E-04
0.13264E 01	57570.	0.40000E-01	750.	12447.87	11834.80	0.53333E-04
0.13664E 01	58230.	0.40000E-01	660.	13123.16	12476.84	0.60606E-04
0.14064E 01	58860.	0.40000E-01	630.	13870.37	13187.25	0.63492E-04
0.14464E 01	59340.	0.40000E-01	480.	14700.73	13976.72	0.83333E-04
0.14864E 01	59790.	0.40000E-01	450.	15626.43	14856.83	0.88889E-04
0.15264E 01	60270.	0.40000E-01	480.	16662.18	15841.57	0.83333E-04
0.15664E 01	60630.	0.40000E-01	360.	17822.58	16944.81	0.11111E-03
0.16064E 01	60930.	0.40000E-01	300.	19120.87	18182.96	0.13333E-03
0.16464E 01	61200.	0.40001E-01	270.	20587.25	19573.32	0.14815E-03
0.16864E 01	61470.	0.40000E-01	270.	22229.59	21134.77	0.14815E-03
0.17264E 01	61650.	0.40000E-01	180.	24073.32	22887.70	0.22222E-03
0.17664E 01	61830.	0.40000E-01	180.	26142.16	24854.65	0.22222E-03
0.18064E 01	61950.	0.40000E-01	120.	28460.57	27058.88	0.33333E-03
0.18464E 01	62040.	0.40000E-01	90.	31054.75	29625.30	0.44444E-03
0.18864E 01	62130.	0.40000E-01	90.	33953.77	32281.54	0.44444E-03
0.19264E 01	62190.	0.40000E-01	60.	37187.58	35356.88	0.66667E-03
0.19664E 01	62220.	0.40000E-01	30.	40788.40	38779.56	0.13333E-02

FATIGUE CRACK PROPAGATION DATA

SPEC NO 1804 LONG GRAIN ROOM AIR TEST FREQ 5 HZ

	P _{MAX} 779.	P _{MIN} 39.	ΔD 0.60440	N _D 0.	B 0.25190	N 2.50000
A	N	DELA	DELN	KMAX	DELK	DADN
0.64440E 00	3780.	0.40000E-01	3780.	10678.53	10143.93	0.10582E-04
0.68440E 00	8220.	0.40000E-01	4440.	10930.93	10383.69	0.90090E-05
0.72440E 00	11250.	0.40000E-01	3030.	11227.83	10665.73	0.13201E-04
0.76440E 00	14820.	0.40000E-01	3570.	11567.02	10987.93	0.11204E-04
0.80440E 00	17460.	0.40000E-01	2640.	11946.25	11348.18	0.15152E-04
0.84440E 00	20100.	0.40000E-01	2640.	12363.47	11744.51	0.15152E-04
0.88440E 00	22680.	0.40000E-01	2580.	12816.89	12175.23	0.15504E-04
0.92440E 00	24630.	0.40000E-01	1950.	13305.47	12639.35	0.20513E-04
0.96440E 00	26520.	0.40000E-01	1890.	13828.79	13136.47	0.21164E-04
0.10044E 01	28440.	0.40000E-01	1920.	14387.38	13667.10	0.20833E-04
0.10444E 01	30030.	0.40000E-01	1590.	14982.83	14232.74	0.25157E-04
0.10844E 01	31740.	0.40000E-01	1710.	15617.94	14836.05	0.23392E-04
0.11244E 01	33030.	0.40000E-01	1290.	16296.69	15480.82	0.31008E-04
0.11644E 01	34140.	0.40000E-01	1110.	17024.77	16172.45	0.36036E-04
0.12044E 01	35220.	0.40000E-01	1080.	17809.04	16917.46	0.37037E-04
0.12444E 01	36180.	0.40000E-01	960.	18658.29	17724.19	0.41667E-04
0.12844E 01	37110.	0.40000E-01	930.	19583.00	18602.61	0.43011E-04
0.13244E 01	37980.	0.40000E-01	870.	20595.55	19564.47	0.45977E-04
0.13644E 01	38790.	0.40000E-01	810.	21710.30	20623.41	0.49383E-04
0.14044E 01	39480.	0.40000E-01	690.	22943.43	21794.80	0.57971E-04
0.14444E 01	40050.	0.40000E-01	570.	24313.42	23096.21	0.70175E-04
0.14844E 01	40620.	0.40000E-01	570.	25840.66	24546.99	0.70175E-04
0.15244E 01	41190.	0.40000E-01	570.	27549.25	26170.04	0.70175E-04
0.15644E 01	41550.	0.40000E-01	360.	29463.18	27988.15	0.11111E-03
0.16044E 01	41970.	0.40000E-01	420.	31610.79	30028.25	0.95238E-04
0.16444E 01	42300.	0.40000E-01	330.	34022.86	32319.55	0.12121E-03
0.16844E 01	42690.	0.40000E-01	390.	36730.62	34891.75	0.10256E-03
0.17244E 01	42900.	0.40000E-01	210.	39771.97	37780.85	0.19048E-03
0.17644E 01	43080.	0.40000E-01	180.	43184.23	41022.28	0.22222E-03
0.18044E 01	43290.	0.40001E-01	210.	47007.63	44654.26	0.19048E-03
0.18444E 01	43440.	0.40000E-01	150.	51287.52	48719.88	0.26667E-03
0.18844E 01	43590.	0.40000E-01	150.	56070.22	53263.15	0.26667E-03

FATIGUE CRACK PROPAGATION DATA

SPEC NO 1805 LONG GRAIN ROOM SALT TEST F 5 HZ

	P _{MAX} 497.	P _{MIN} 25.	ΔD 0.64580	N _D 0.	B 0.25260	N 2.50000
A	N	DELA	DELN	KMAX	DELK	DADN
0.68580E 00	4980.	0.40000E-01	4980.	6960.71	6610.58	0.80321E-05
0.72580E 00	8340.	0.40000E-01	3360.	7150.57	6790.89	0.11905E-04
0.76580E 00	11160.	0.40000E-01	2820.	7367.31	6996.73	0.14184E-04
0.80580E 00	13650.	0.40000E-01	2490.	7609.46	7226.70	0.16064E-04
0.84580E 00	15430.	0.40000E-01	2280.	7875.64	7479.53	0.17544E-04
0.88580E 00	17820.	0.40000E-01	1890.	8164.94	7754.28	0.21164E-04
0.92580E 00	19800.	0.40000E-01	1980.	8476.61	8050.23	0.20202E-04
0.96580E 00	21360.	0.40000E-01	1560.	8810.34	8367.17	0.25641E-04
0.10058E 01	22800.	0.40000E-01	1440.	9166.55	8705.46	0.27777E-04
0.10458E 01	24240.	0.40000E-01	1440.	9546.24	9066.06	0.27777E-04
0.10858E 01	25500.	0.40000E-01	1260.	9951.17	9450.62	0.31746E-04
0.11258E 01	26670.	0.40000E-01	1170.	10384.09	9861.77	0.34184E-04
0.11658E 01	27540.	0.40000E-01	870.	10848.51	10302.82	0.45977E-04
0.12058E 01	28560.	0.40000E-01	1020.	11348.80	10777.95	0.59210E-04
0.12458E 01	29340.	0.40000E-01	780.	11890.67	11242.56	0.51742E-04
0.12858E 01	29940.	0.40000E-01	600.	12480.87	11853.07	0.66667E-04
0.13258E 01	30690.	0.40000E-01	750.	13127.19	12466.86	0.53333E-04
0.13658E 01	31290.	0.40000E-01	600.	13836.78	13142.68	0.66667E-04
0.14058E 01	31800.	0.40000E-01	510.	14626.26	13890.54	0.76431E-04
0.14458E 01	32280.	0.40000E-01	480.	15501.15	14721.43	0.83333E-04
0.14858E 01	32730.	0.40000E-01	450.	16476.54	15647.75	0.88888E-04
0.15258E 01	33150.	0.40000E-01	420.	17567.85	16604.17	0.95238E-04
0.15658E 01	33510.	0.40000E-01	360.	18790.26	17645.09	0.11111E-03
0.16058E 01	33720.	0.40000E-01	210.	20162.41	19148.22	0.14048E-03
0.16458E 01	34050.	0.40000E-01	330.	21703.24	20811.55	0.12121E-03
0.16858E 01	34320.	0.40000E-01	270.	23433.27	22244.56	0.14048E-03
0.17258E 01	34530.	0.40000E-01	210.	25375.79	24049.79	0.14048E-03
0.17658E 01	34740.	0.40001E-01	210.	27555.24	26169.22	0.19048E-03
0.18058E 01	34860.	0.40000E-01	120.	29994.16	28449.23	0.33333E-03
0.18458E 01	35010.	0.40000E-01	150.	32731.44	31045.06	0.26667E-03
0.18858E 01	35160.	0.40000E-01	150.	35766.53	33946.43	0.26667E-03
0.19258E 01	35280.	0.40000E-01	120.	39143.68	37222.21	0.33333E-03
0.19658E 01	35470.	0.40000E-01	120.	42987.59	40825.27	0.33333E-03
0.20058E 01	35480.	0.40000E-01	60.	47203.77	44829.38	0.66667E-03

APPENDIX E

CALCULATION OF POTENTIAL WEIGHT SAVINGS IN THE YUH-61A HORIZONTAL-STABILIZER SPAR FITTING

The fatigue life of a helicopter component is based on a design-allowable fatigue-endurance limit which must be used to account for variables other than basic material properties affecting the fatigue performance of helicopter components.

The design-allowable fatigue-endurance limit for helicopter components is established by reducing the mean-endurance limit of material-coupon data to account for component-coupon size effects and to accommodate the statistical probabilities of component failure.

Results of the Task III material-coupon tests indicate that 7475-TMT1 has a higher mean-endurance limit than 7075-T73 has for the design conditions which apply to the horizontal stabilizer. The corresponding design-allowable fatigue-endurance limit for each material is determined as follows:

	<u>7075-T73</u>	<u>7475-TMT1</u>
Mean-Endurance-Limit Coupon Data		
Stress Ratio, $R = 0.05$	20,000 psi	21,000 psi
6.7-Inch Forging		
Longitudinal Properties		
(Mean- 3σ), 13%		
Coefficient of Variation	13,169 psi	13,829 psi
Reduction for		
Size Effect, $\left\{ \frac{M-3\sigma}{1.95} \right\}$	6,753 psi	7,092 psi

An adjustment is necessary for stress ratio, R . To estimate the allowable at $R = 0.52$, the Goodman diagram for 2-inch forgings, Figure 110, is used.

$$\frac{\text{Design Allowable } R = 0.52}{\text{Design Allowable } R = 0.05} = \frac{\text{Endurance Limit @ } 5 \times 10^7 \text{ cycles (} R = 0.52 \text{)}}{\text{Endurance Limit @ } 5 \times 10^7 \text{ cycles (} R = 0.05 \text{)}}$$

$$\text{Design Allowable } R = 0.52 = \left\{ \frac{14,700}{23,000} \right\} \text{Design Allowable } R = 0.05 =$$

$$0.64 \text{ Design Allowable } R = 0.05$$

<p>DESIGN-ALLOWABLE FATIGUE-ENDURANCE LIMIT</p>

7075-T73
4,322 psi

7475-TMT1
4,533 psi

Adjustment for Stress
Concentration Factor, $K_t = 3.5$

Design Allowable	=	1,235 psi	1,295 psi
K_t			

7475-TMT1 alloy demonstrates a design allowable which is 5 percent higher than the design allowable for 7075-T73.

A 5-percent increase in allowable stress translates into a 5-percent weight reduction:

$$\text{Stress} = \frac{\text{Load}}{\text{Area}}$$

and

$$\begin{aligned} \text{Weight/unit length} &= (\text{volume/unit length}) \times \text{material density} \\ &= (\text{area} \times 1) \times \rho. \end{aligned}$$

Given the same load, an allowable stress of 1,235 psi generates a requirement for an area,

$$A = \frac{\text{Load}}{\text{Allowable}} = \frac{1,560 \text{ lb}}{1,235 \text{ psi}} = 1.263 \text{ in.}^2 \text{ and an allowable stress of 1,295 psi generates a requirement for an area, } A = \frac{1,560 \text{ lb}}{1,295 \text{ psi}} = 1.205 \text{ in.}^2$$

The weight relationship is then

$$\begin{aligned} \frac{\text{Weight}_{7075-T73}}{\text{Weight}_{7475-TMT1}} &= \frac{(\text{Area}_{7075-T73} \times 1) \times \rho}{(\text{Area}_{7475-TMT1} \times 1) \times \rho} \\ \text{Weight}_{7475-TMT1} &= \text{Weight}_{7075-T73} \frac{\text{Area}_{7475-TMT1}}{\text{Area}_{7075-T73}} \\ &= \text{Weight}_{7075-T73} \left\{ \frac{1.205}{1.263} \right\} \\ &= \text{Weight}_{7075-T73} = (0.95) \end{aligned}$$

or, conversely, a 5-percent weight reduction.

APPENDIX F

PREDICTED WEIGHT SAVINGS IN THE YUH-61A ANTITORQUE- ROTOR COLLECTIVE-PITCH SLIDER SIZED TO DAMAGE TOLERANCE

REQUIREMENTS

The predicted crack growth in the pitch slider shown in Figure 155 is based on an RMS stress in the slider, the material properties measured in Task III, the crack-stress model for a hollow cylinder, and the Paris equation for crack-growth rate. The RMS stress is determined as shown in Figure F1.

Fatigue-crack-propagation rates for 7075-T73 (Figure 127) and 7475-TMT2 (Figure 146) and short-transverse fracture-toughness values for 6.7-inch forging (Table 21) have been used in this example. The Paris equation was selected for illustration purposes to present a simpler computation. The coefficients for fatigue-crack propagation-rate data from Figures 127 and 146 are:

<u>7075-T73</u>	<u>7475-TMT2</u>
$C_p = 6.0493 \times 10^{-7}$	$C_p = 8.0902 \times 10^{-8}$
$n_p = 1.8329$	$n_p = 2.03514$

The crack-stress model for stress-intensity factor and the computation procedure are shown in Figure F2.

A weight savings due to the improvement in fracture properties can be demonstrated.

Based on the measured short-transverse fracture-toughness value for 6.7-inch 7075-T73 forging, the pitch slider can sustain a 4.60-inch crack prior to catastrophic failure. This is based on the geometry of the slider and the relationship for stress-intensity factor:

$$K_{IC} = \sigma_{\text{limit}} \sqrt{\pi a_c} \quad f_{(a_c)}.$$

Using this relationship and the increased fracture toughness of 7475-TMT2, one can determine that:

$$\sigma_{\text{limit } 7475\text{-TMT2}} = \left(\frac{K_{IC \text{ TMT2}}}{K_{IC \text{ T73}}} \right) \sigma_{\text{limit T73}}$$

$$\sigma_{\text{limit } 7475\text{-TMT2}} = (1.48) \sigma_{\text{limit T73}}.$$

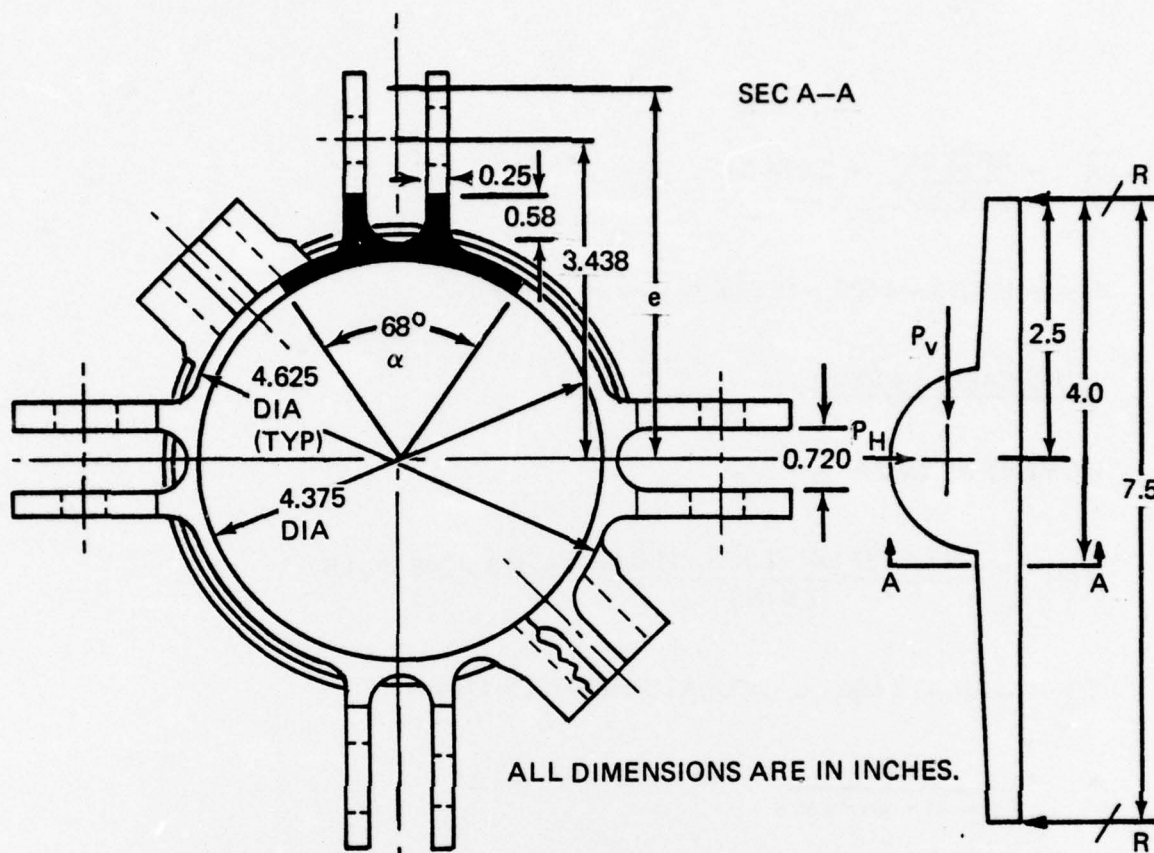
See Figure F3.

An increase in the allowable stress translates into a decrease in weight as shown in Appendix E. Hence, a 48-percent increase in allowable stress results in a 48-percent decrease in weight.

As shown in Figure 153, the slower crack-growth rate in 7475-TMT2 can be advantageous in reducing weight.

Crack-growth rate is directly affected by stress level. By increasing the RMS stress in the 7475-TMT2 slider, a tradeoff in weight is possible, with the maximum weight reduction occurring when the crack-growth rates are identical for the 7475-TMT2 and 7075-T73 sliders.

By an iterative solution, the 7475-TMT2 slider can demonstrate the same failsafe life as the 7075-T73 slider while functioning at a stress level of $890 \pm 1,650$ psi. Compared to the 7075-T73 slider at $700 \pm 1,296$ psi, this shows a 27-percent increase in allowable stress and, consequently, a 27-percent reduction in weight.



SECTION A-A PROPERTIES

$$\bar{X} = \frac{2 \sin \alpha (R^3 - r^3)}{3 \alpha (R^2 - r^2)} = \frac{2 (.93) (2.3125^3 - 2.1875^3)}{3 (1.19) (2.3125^2 - 2.1875^2)} = 1.759 \text{ IN.}$$

$$\text{AREA} = (R^2 - r^2) \alpha = (2.3125^2 - 2.1875^2) (1.19) = 0.67 \text{ IN.}^2$$

$$I_{yy} = \frac{\alpha}{4} (R^4 - r^4) \left(1 + \frac{\sin \alpha \cos \alpha}{\alpha} \right) - \frac{1}{\alpha (R^2 - r^2)} \left(\frac{2 \sin \alpha (R^3 - r^3)}{3} \right)^2$$

$$= \frac{1.19}{4} (2.3125^4 - 2.1875^4) \left(1 + \frac{(0.93) (0.376)}{1.19} \right) - \left(\frac{1}{(1.19) (2.3125^2 - 2.1875^2)} \right) \left(\frac{2 (0.93) (2.3125^3 - 2.1875^3)}{3} \right)^2 = 0.12317 \text{ IN.}^4$$

SECTION	AREA	X	Ax	Ax ²	I _{yy}
CIR SECTION	0.67	1.759	1.178	2.073	0.12317
RECTANGULAR	0.29	2.603	0.755	1.964	0.00813
Σ	0.96		1.933	4.037	0.13130

Figure F1. Stress Analysis of Tail-Rotor Collective-Pitch Slider for YUH-61A (Sheet 1 of 2).

$$\bar{X}' = \frac{1.933 \text{ IN.}^3}{0.96 \text{ IN.}^2} = 2.014 \text{ IN.}$$

$$I_{yy} = 0.1313 + 4.037 - (1.933)(2.014) = 0.276 \text{ IN.}^4$$

LOAD CALCULATION:

MOMENT AT SEC A-A = M_A

$$M_{PH} = \frac{(141 \pm 261 \text{ LB})(2.5 \text{ IN.})(4.0 \text{ IN.})}{(7.5 \text{ IN.})} = 188 \pm 348 \text{ IN.-LB}$$

TO CALCULATE M_{PV} , CALCULATE SHEAR CENTER e :

$$e = \frac{2R}{(\pi - \theta) + \sin \theta \cos \theta} [(\pi - \theta) \cos \theta + \sin \theta]$$

$$e = \frac{2(2.25)}{(3.14159 - 1.96) + (0.9205)(0.39073)} [(3.14159 - 1.96)(0.39073) + 0.9205]$$

$$e = 4.035 \text{ IN.}$$

$$\text{MOMENT ARM} = (4.035 \text{ IN.} - 3.438 \text{ IN.}) = 0.597 \text{ IN.}$$

$$M_{PV} = (0.597 \text{ IN.})(141 \pm 261 \text{ LB}) = 84 \pm 156 \text{ IN.-LB}$$

$$M_A = M_{PH} + M_{PV} = 272 \pm 504 \text{ IN.-LB}$$

$$f_b = 0.81 (272 \pm 504 \text{ IN.-LB}) (0.875 \text{ IN.}) / (0.276 \text{ IN.}^4) = 700 \pm 1,296 \text{ psi (RMS)}$$

Figure F1. Stress Analysis of Tail-Rotor Collective-Pitch Slider for YUH-61A (Sheet 2 of 2).

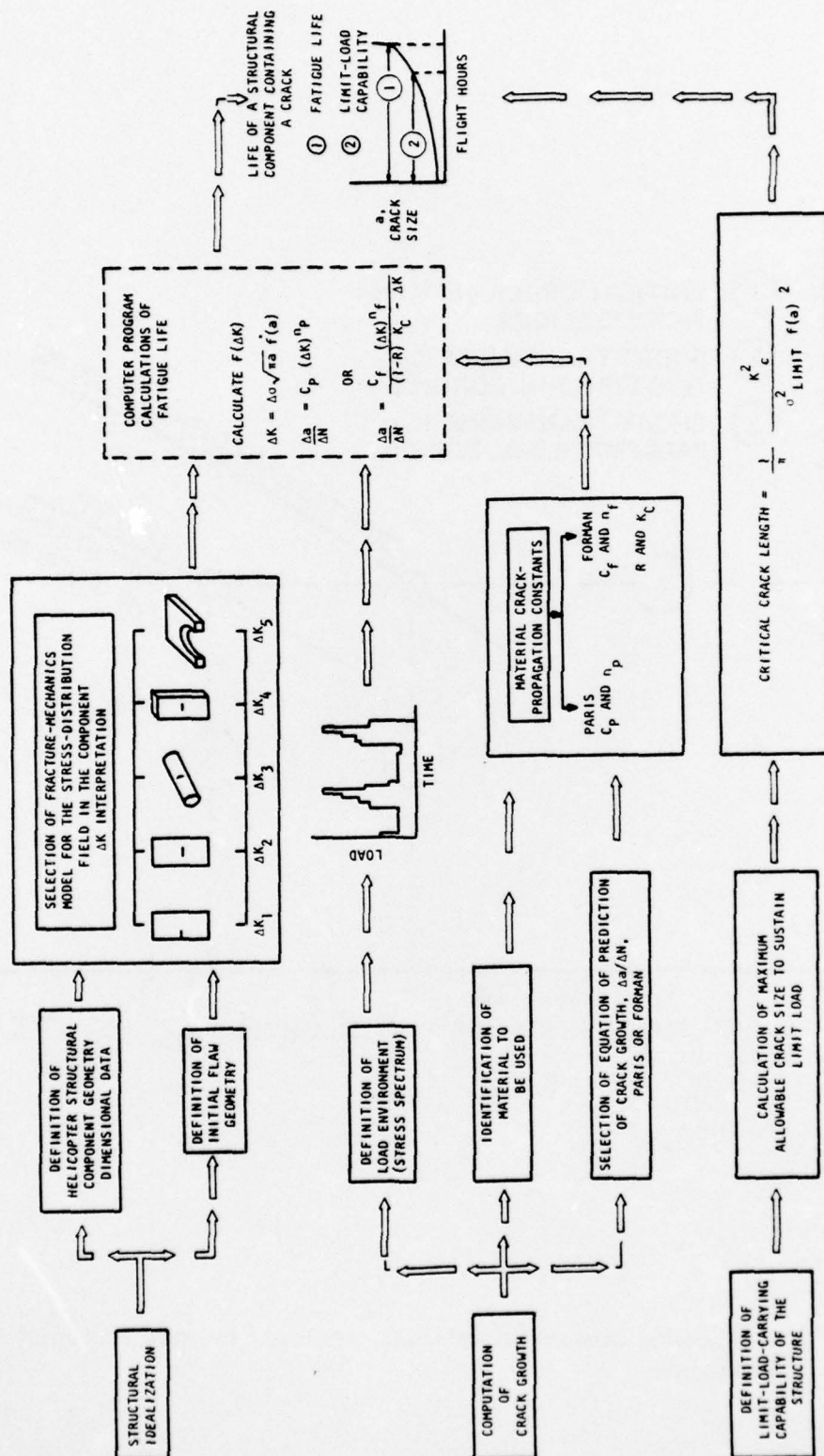


Figure F2. Computation Procedure and Crack-Stress Model for Stress-Intensity Factor.

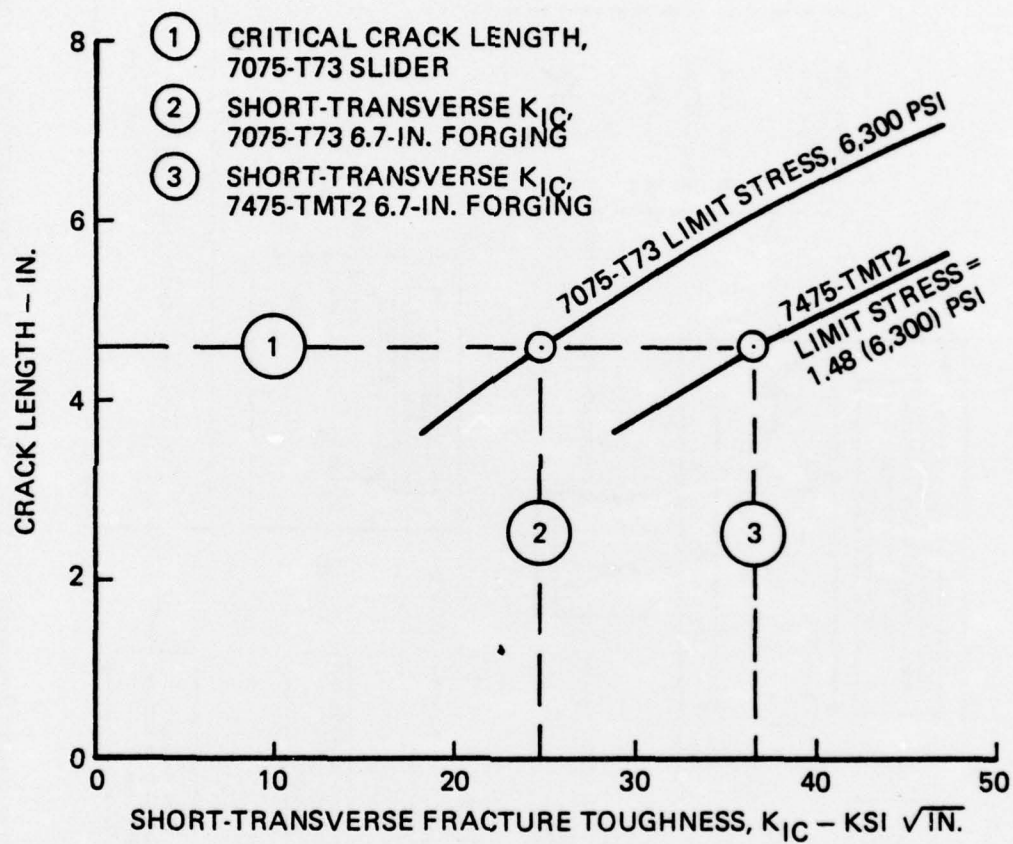


Figure F3. Relationship Between Critical Crack Length and Fracture Toughness of Pitch Slider.

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IMPROVEMENT OF HELICOPTER FORGINGS BY CONTROLLED SOLIDIFICATION & THER-
MAL-MECHANICAL TREATMENTS(U)

JOSEPH C. ZOLA.

UNCLASSIFIED BOEING VERTOL COMPANY, PHILADELPHIA, PA.

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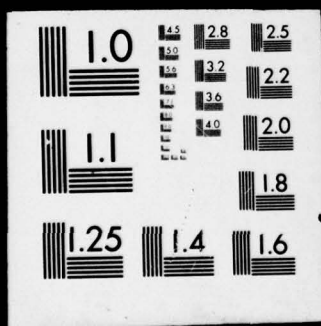


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Cover Page

Form DD 147

P. 97

P. 199

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P. 199

~~Addition~~

ERRATA SHEET - AVSCOM REPORT NO. 76-41

DA 03/357

Cover Page	Change Contract Number from "A25-74-C-0448" to "DAAA25-74-C-0448"
Form DD 1473	Change 4. Title to "Improvement of Helicopter Forgings <u>By</u> Controlled Solidification and Thermal-Mechanical Treatments"
P. 97	Insert word "and" in last sentence so that statement reads ".... a recrystallized-plus-hot-worked structure, and in"
P. 199	In first paragraph insert word "and" in first sentence so that paragraph reads "....20 per-cent better toughness and fatigue"
P. 199	In item 1. change "TMT" to "ITMT"
P. 199	In item 3. change "62" to "75"
P. 199	In item 4. change "TMT" to "ITMT"
Addition	Distribution List (See attachments)